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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

CONDUCTING EXPEDITIONARY OPERATIONS IN THE CONTESTED LITTORALS

by

Team Gator
Cohort SEA 21B

June 2015

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The United States armed services have identified capability gaps in the areas of company-sized raid and sustainment operations in contested littoral environments. Multiple joint platform packages can be employed to provide the required mission capabilities to fill the gap. This thesis identifies the operational, functional, and physical architecture and effectiveness of mission packages necessary to provide capabilities associated with littoral sustainment operations. Physical architecture configurations are evaluated using discrete event modeling. Cost and performance estimates for the mission packages are presented in order to provide the decision maker tools for identifying which alternative provides the most cost-effective solution for the needs of a scenario's stakeholders. This thesis report concludes by identifying potential assets that would provide cost-effective support of littoral operations. Feasible alternatives provide varying levels of effectiveness in terms of average deployment time and percentage of threats successfully affected.

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ABSTRACT

The United States armed services have identified capability gaps in the areas of company-sized raid and sustainment operations in contested littoral environments. Multiple joint platform packages can be employed to provide the required mission capabilities to fill the gap. This thesis identifies the operational, functional, and physical architecture and effectiveness of mission packages necessary to provide capabilities associated with littoral sustainment operations. Physical architecture configurations are evaluated using discrete event modeling. Cost and performance estimates for the mission packages are presented in order to provide the decision maker tools for identifying which alternative provides the most cost-effective solution for the needs of a scenario's stakeholders. This thesis report concludes by identifying potential assets that would provide cost-effective support of littoral operations. Feasible alternatives provide varying levels of effectiveness in terms of average deployment time and percentage of threats successfully affected.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	anti-access/area denial
AFSB	afloat forward staging base
AoA	analysis of alternatives
AOI	area of interest
AOR	area of responsibility
ARG	amphibious readiness group
ASBM	anti-ship ballistic missile
ASCM	anti-ship cruise missile
ASM	anti-ship missile
ARM	anti-radiation missile
ASW	anti-submarine warfare
C2	command and control
C4I	command, control, communications, computers, and intelligence
CBA	Capabilities-Based Assessment
COA	course of action
COI	Critical Operational Issue
CONOPS	concept of operations
DOD	Department of Defense
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy
FFBD	functional flow block diagram
GCE	ground combat element
Helo	helicopter
HTML	hypertext markup language
ISR	intelligence, surveillance, and reconnaissance
JCIDS	Joint Capabilities Integration and Development System
JHSV	joint high-speed vessel
JLENS	Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System
JPADS	Joint Precision Airdrop System

JROC	Joint Requirements Oversight Council
KPP	Key Performance Parameter
LCAT	landing catamaran
LCS	littoral combat ship
LCU	landing craft utility
LHA	general purpose amphibious assault ship
LHD	landing helicopter dock
LPD	landing platform dock
MAGTF	Marine air and ground task force
MANA	Map Aware Non-uniform Automata
MANPAD	man-portable air defense
MCM	mine countermeasures
MCWP	Marine Corps war publication
MEB	Marine expeditionary brigade
MEU	Marine expeditionary unit
MLP	mobile landing platform
MOE	Measure of Effectiveness
MOP	Measure of Performance
N9I	Naval Warfare Integration Division
NATO	North Atlantic Treaty Organization
NM	nautical mile
NPS	Naval Postgraduate School
NSM	Naval strike missile
OPAREA	area of operations
OPS	operations
OTH	over-the-horizon
PLA	People's Liberation Army
PLAN	People's Liberation Army – Naval component
RAID	Rapid Aerostat Initial Deployment
RHIB	rigid-hull inflatable boat
RTB	return to base
SE	systems engineering

SIMIO	Simulation Modeling framework based on Intelligent Objects
SOF	special operations forces
SOS	system-of-systems
SSGN	nuclear guided-missile submarine
SOR	System Operating Requirement
STR	System Technical Requirement
SUW	surface warfare
TPM	Technical Performance Measure
UAV	unmanned aerial vehicle
UNTL	Universal Naval Task List
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy

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EXECUTIVE SUMMARY

The Systems Engineering and Analysis 21 Bravo (SEA 21B) Integrated team project represents a cross campus multi-disciplinary effort at the Naval Postgraduate School (NPS) to investigate Expeditionary Operations in the Contested Littorals. The project team's sixteen members hale from both military and civilian backgrounds representing the Army, Navy, Air Force, and defense industry from the nations of the United States, Singapore, and Israel. The SEA 21B team capitalized on the diversity of its membership by bringing a wealth of real-world tactical and technical experience to bear on the assigned team tasking.

The SEA 21B team was tasked to investigate the feasibility of over-the-horizon (OTH) amphibious raid capabilities from beyond the reach of modern anti-access / area denial (A2AD) weapons systems using small unit formations. Our goal was to design a fleet system of systems to include a concept of operations (CONOPS), potential force packages, and command and control courses of action (COA) to deploy and support company-sized, rapid response expeditionary assets in a contested littoral region in the 2025–2030 timeframe.

We applied the systems engineering (SE) approach to craft our tasking statement and the SE method to determine the best solution. The first step in our SE design process was to define the problem. Our team worked with our primary sponsor, The Naval Warfare Integration Division (N9I), and other potential stakeholders to refine the problem statement in order to reach a consensus on what future capabilities we were going to develop. After we established an agreed upon direction for our team, we were ready for the second major step in the SE process. The second step in our SE process was to generate a series of possible solutions that would act as COAs we could recommend to our primary sponsor. To generate a set of possible solutions, the team divided into three main groups that each focused on an Army, Navy, and Marine service-centric solution. The team's approach was to utilize legacy systems from each of the services with realistic options for near-term future system development. Each group created a set of possible COAs using service-based legacy systems. Afterward, the final step in our SE approach

was to evaluate each COA using an Analysis of Alternatives (AoA) approach. The result of the AoA ultimately yields a potential collection of system COAs that would best meet the needs of the sponsor and system stakeholders.

Due to the assigned timeframe of ten to fifteen years in the future, each design group focused on exploring platforms that either are currently in the United States' inventory, or are nearing the final stages of procurement. Primarily, the Air Force and Army group explored a variety of air-drop techniques utilizing C-2 and C-130 cargo aircraft. The Navy focused on ships and aircraft currently in the fleet, such as the littoral combat ship (LCS), joint high-speed vessel, MV-22 Osprey, and special operations capable submarines. Additionally, the Navy explored platforms currently in use by allied navies that could be rapidly procured and deployed in an off-the-shelf manner. Exploration led to the inclusion of a long-range landing craft, similar to France's catamaran-style L-CAT.

Once each group had thoroughly researched and agreed on its available platforms, they were tasked with developing a series of concepts of operation (CONOPS) that could be employed to meet the requirement of rapidly deploying a company-sized landing force. The Air Force group focused on developing a capability of parachuting personnel and heavy equipment precisely onto a small island while the Navy group developed a series of options for delivery of personnel and equipment. These options ranged from employing the LCS as a miniature amphibious ship, to submarine insertion, to OTH landing craft operations. Concurrently, the Army and Marine Corps groups developed platoon-sized force packages, each group with a particular mission in mind. The logic was to enable a land force to tailor its composition to match an expected threat precisely. For example, if a landing force was anticipating being dropped off on an island, without sustained naval or air support, they might need an intelligence, surveillance, and reconnaissance (ISR) platoon to operate unmanned surveillance vehicles, an Air Defense platoon armed with surface-to-air missiles, and a Sea Control platoon armed with containerized anti-ship cruise missiles. Once the platoons were developed, these groups developed a series of potential deployment packages based on various plausible threats.

The team created and utilized dozens of models, incorporating stochastic, deterministic, and tabular methods in order to quantify both feasible options within each model and each COA's performance in relation to each Measure of Effectiveness (MOE). Additionally, several models pertaining to specific COAs were created to explore specific aspects of a particular COA. The tools used to create the models included SIMIO™, a visual object oriented discrete modeling system; MANA for agent based simulation; Microsoft Excel™ for both stochastic and deterministic general purpose modeling; and a custom 3-D JavaScript simulation capable of quantifying a COA's ability to deliver U.S. and/or allied (Blue) forces to a location before adversary (Red) forces can arrive. These models are based on multiple mathematical methodologies including simple tabulation, statistical binomial distribution, trigonometry, and Hughes' salvo equations (Hughes 1988).

Analysis of the models provided insight into the performance of each COA, the ability to quantify that performance, and the ability to compare that performance to other COAs. Additionally, the models provided dimensions to search for the "best" option irrespective of the specifications of a COA. For example, while all COAs are compared based on the blue forces originating from the same location the models provide insight into COA performance if blue forces originated from a different location.

The final goal of SEA 21B was to develop a menu of force package employment options for decision makers. As it is impossible to anticipate every eventuality, or the factors that might be most important in any given scenario, our most useful contribution would be in developing a variety of options, each with its own strengths and weaknesses. By analyzing the strong suits and pitfalls for each CONOP, decision makers are provided with a master menu, which would provide options for a wide range of eventualities.

The resulting team product was the development of a system trade space our stakeholders and decision makers can utilize to evaluate potential system configurations based upon stakeholder need

An example of a force package menu in practice would be to have multiple existing Department of Defense (DOD) systems and their various capabilities integrated

into one System of Systems (SOS) for short notice reaction to rising threats anywhere in the world. By combining assets from the Air Force, Navy, Marines and the Army together into once systems capable of producing different combinations of force packages an emergence of new capabilities occurs.

A hypothetical scenario for this system would be to have an aggressive state actor advancing towards a disputed island territory for the purposes of seizing the island and establishing and A2AD environment. In addition, once the island is seized by an aggressive state there is little chance that the situation will resolve itself quickly without the threat of armed escalation. Therefore, the DOD must react to this threat in a timely manner and deploy DOD assets to the disputed island territory before another state actor arrives to make a claim.

By experimenting and combining different DOD systems our team discovered different COAs suitable for a range of scenarios. One such COA would be to have MV-22 Ospreys leave forward operating bases in the South Pacific with Marines at specific times to mass a landing force together with C-17s loaded with paratroopers out of Hawaii while support is delivered via navy ships forward deployed to friendly ports in the area. Reconnaissance to support the mission would be an integrated effort across the DOD using an integrated network of satellites, stationary sensors, and drones. Planners could use a fore package menu system to assess the threat and available options quickly. Afterwards, decision makers could select the force package that best suits the needs of the tactical situation. Is getting to the island quickly important? Then delivery via air is selected and a combination of support that can sustain light airborne infantry in an island environment is also selected.

We found through analysis that Air Force C-17s and C-130s are the best options for delivery of an expeditionary force when considering average performance ability across the entire range of inputs we explored. It is possible for individual leader inputs to change the most favorable anticipated outcomes based on reconfiguration of MOE weights on a case-by-case basis. Such priority-result sets were detailed in Chapter XI and Appendix F. representing our stakeholders, our team found speed to be the top priority. Therefore, to accomplish the given mission we submit for recommendation a force

package that utilizes COA E (Air Force C-17 and C-130) aircraft deployment of land force packages COA 6 for small islands or COA 8 for large islands

Unfortunately, the ability to network and pull disparate systems together quickly, in order to seize an island, does not exist. For instance, deploying a C-17, with C-130s, supported via Littoral Combat ships (LCS) using airborne Soldiers and/or Marines to seize territory, does not exist in a form capable of reacting quickly to global threats. Current DOD practices and doctrine do allow for joint operations. However, the process is slow—taking days to weeks, or longer to plan and execute. Our project demonstrates that current DOD capabilities within existing service inventories are well suited to taking on the challenge of quickly deploying to high threat areas as an integrated system. As a result, our project team recommendation is for the DOD to develop the plans to seize small island areas on short notice in the A2AD environment using existing capabilities integrated for a short-notice flexible response.

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I. INTRODUCTION

A. PROJECT TEAM

The Systems Engineering and Analysis 21 Bravo (SEA 21B) integrated team project represented a cross campus multidisciplinary effort at the Naval Postgraduate School (NPS) to investigate Expeditionary Operations in the Contested Littorals. The project team's sixteen members hailed from both military and civilian backgrounds representing the Army, Navy, Air Force, and defense industry from the nations of the United States, Singapore, and Israel. The SEA 21B team capitalized on its' members experience and as such brought a wealth of real-world tactical and technical experience to bear on the assigned team tasking. Table 1 lists the students, their backgrounds, and their particular areas of functional expertise.

Table 1. SEA21A Team Members

Team Member	Nation	Service/ Company	Specialty
Juan Carleton	USA	Army	Aviation, Ground Operations (OPS)
Steven Fischbach	USA	Navy	Aviation, ISR, Carrier OPS
Brandon Naddell	USA	Navy	Surface Warfare, Surface OPS
Francisco Martinez	USA	Navy	Undersea Warfare, Submarine OPS
Eugene Lee	Singapore	ST Kinetics	Land Armored Track Platforms
Reginald Johnson	USA	Navy	Aviation, Airborne Battle Management, Datalink
Yoav Shaham	Israel	IDF	Software Engineer
Cheng Hong Low	Singapore	ST Aerospace	Airborne Sensors and Software Engineer
Wei San Lee	Singapore	ST Electronics	Shipboard Integrated Communications
Jordan Bradford	USA	Navy	Surface Warfare, Missile Warfare
Brian Piggrem	USA	Navy	Airborne ISR, Anti-Submarine/ Anti-Surface Warfare
Edwin Tan	Singapore	Army	Combat Engineer, Crossing OPS
Zibin Chen	Singapore	Army	Artillery, Strike OPS
Bing Yong Lim	Singapore	Air Force	Ground Based Air Defense
Matthew Kleine	USA	NAVY	SWO
Damion Jones	USA	Navy	Surface Warfare, Amphibious and Mine Warfare OPS
Alfred Williams	USA	Navy	Submarine OPS, Information Dominance

The role of the students on the project team is that of a lead systems engineering group working in cooperation with stakeholders who have interests in the project topic. Students are expected to integrate ideas and requirements from fellow NPS students and faculty from various academic departments at NPS as well as stakeholder information and expertise from outside the NPS within the public and private sectors.

1. Team Organization

The SEA 21B team initially organized into three groups that each supported a pillar of the team's collective research plan. The three pillars shown in Figure 2 represent efforts by Group Alpha (offensive functions), Group Bravo (defensive functions), and Group Charlie (stasis/deterrence functions) to develop preliminary architectures and perform functional analyses. The plan was for these three groups to approach the problem statement from three independent interest areas of thought. After gathering the requisite knowledge base, each group then explored an individual solution with an in-depth analysis.

The team's task was to look at both offensive and deterrence operations within an A2AD environment while leveraging almost exclusively United States military capabilities delivered by components of its land, sea, and air forces. Given our knowledge of lessons learned from previous SEA projects and our requirement to tailor the problem statement, to our particular interests, it was prudent for our team to organize in such a way that supported joint operations in order for our team to explore force options from all services.

Figure 1 shows the breakdown of the SEA 21B team into three separate groups that worked to support each other's tasking throughout each phase of the Project. Phases were built around the three-quarter NPS system and deliverables were established for each academic quarter.

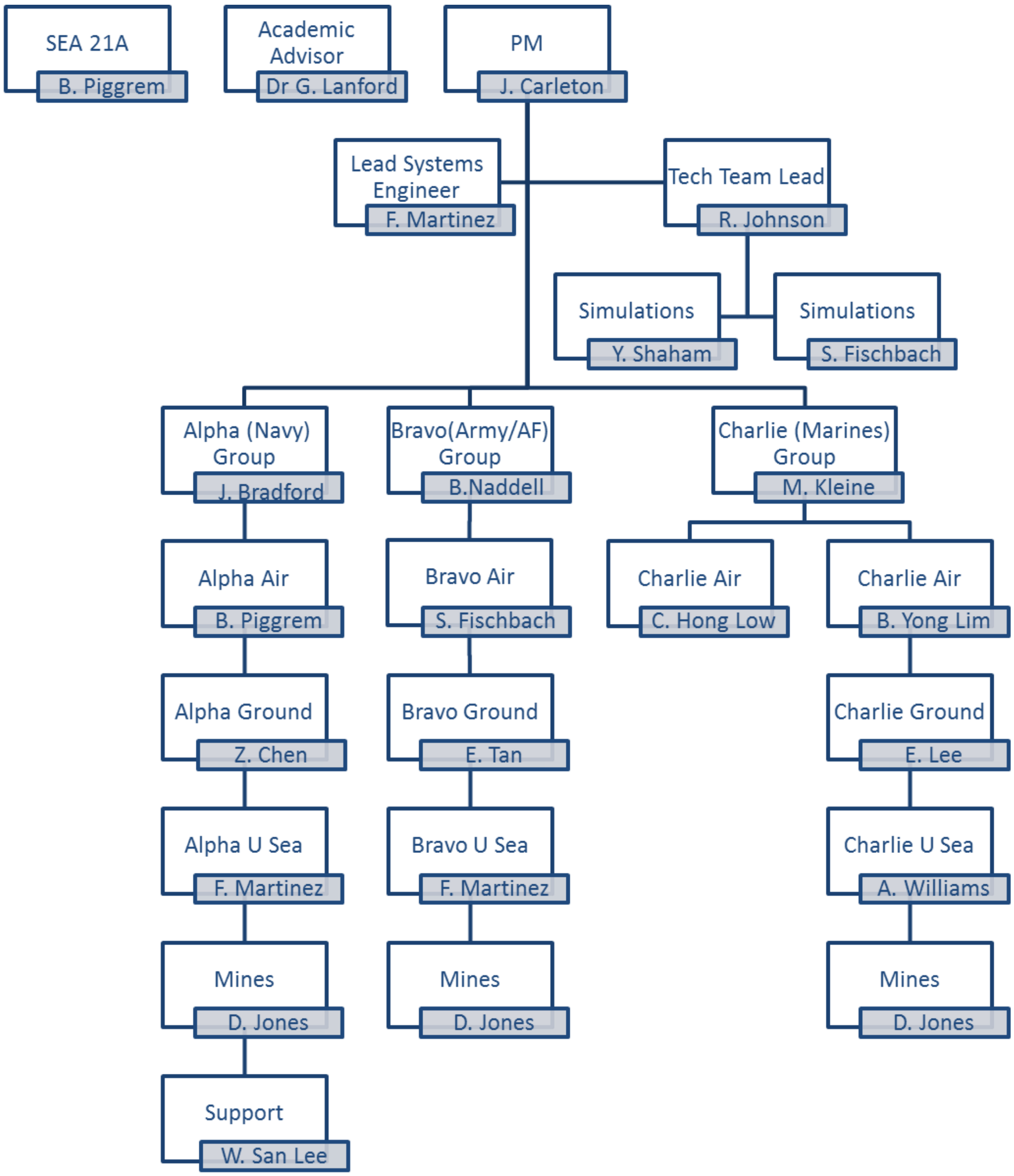

Figure 1. SEA 21B Project Team Initial Organization

Team members from various backgrounds organized into three groups in order to capitalize on the perspectives and specialization of each member and to represent each of the major functional domains needed to address the tasking as shown in Figure 1. The general breakdown of positions and responsibilities throughout the duration of the project

reflected expertise in areas such as naval surface warfare, ground operations, intelligence, aviation, and other specific operational areas (OAs) within the Department of Defense. The three groups (Alpha, Bravo, and Charlie) eventually transformed into solution specific research groups dedicated to the Naval, Marine, and joint Army/Air Force solutions. Finally, our technical group worked concurrently with each of the first three groups to produce relevant analytical models that we would later use to evaluate various potential systems as a part of our Analysis of Alternatives (AoA).

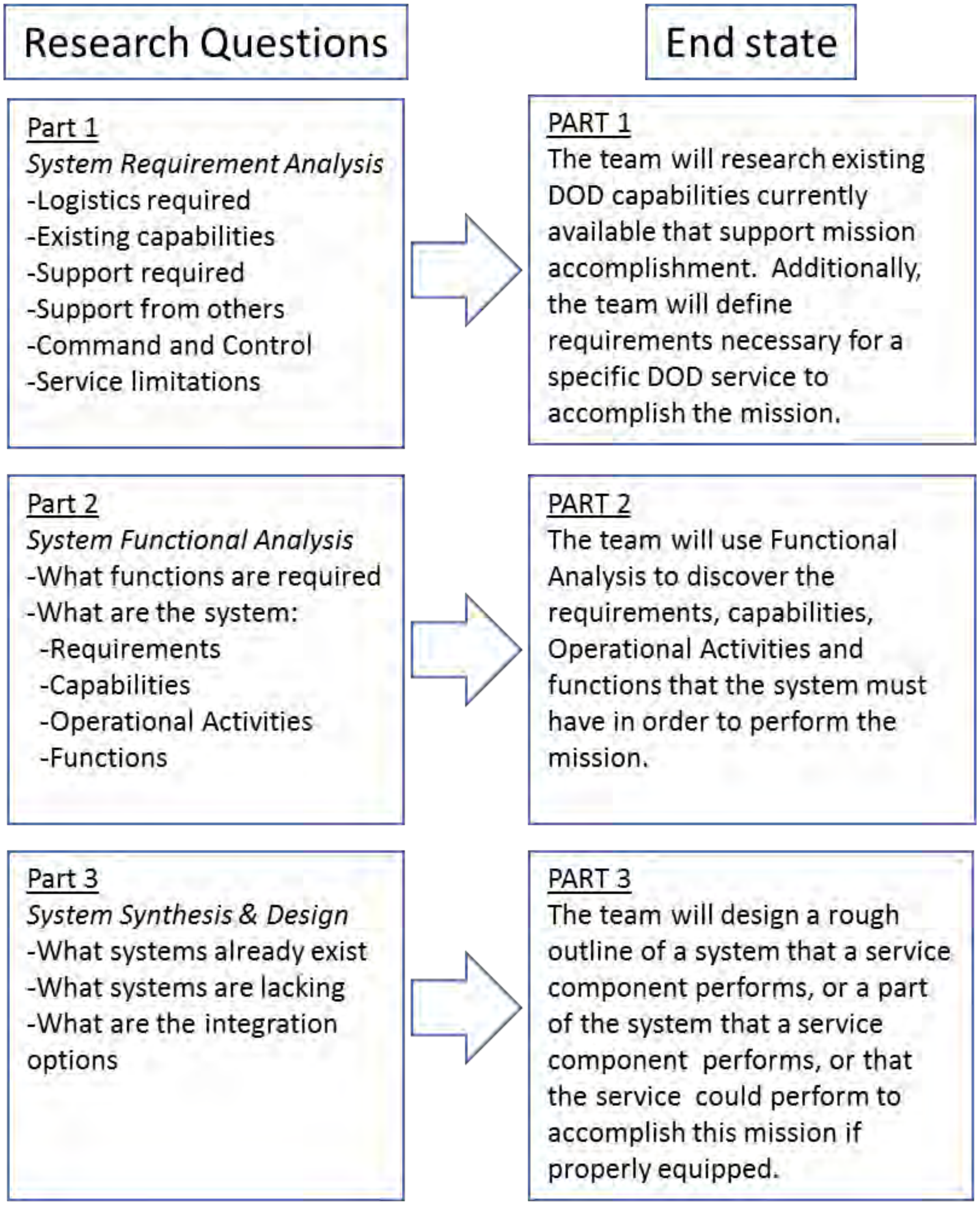

Figure 2. Solution Research Areas

Figure 2 shows the group research areas that eventually became the primary framework the project team proceeded under while researching potential solutions. A primary assumptions our team made is that our solution will likely be performed by either a specific branch or joint force originated from the Department of Defense (DOD). Dividing team members into groups by DOD service allowed group members to

focus on solution areas that were realistic, based upon group member expertise. The groups became simply known as the Navy, Marine, and Army / Air Force groups.

2. Technical Group

The SEA Capstone Project is a cross campus effort that brings together students from outside of the Systems Engineering curriculum to participate in the systems engineering process with SEA curriculum students. The added value for the team is that some of the student team members bring modeling and simulation knowledge that helps support solution development. Since modeling and simulation knowledge is a niche area of expertise the team elected to create a group that would focused solely on the modeling and simulation efforts to support the three DOD groups in the evaluation of various courses of action (COA) solutions. The Technical group was responsible for developing the technical tools necessary to support the team's research and final solution space analysis. The Technical group worked with the other groups to develop specific models for each COA. The Technical group also organized the team's efforts during AoA portion of the SE process.

B. CROSS CAMPUS TOPIC EFFORT

The SEA 21B team project is conducted as one part of the NPS Warfare Innovation Continuum, "Warfighting in the Contested Littorals" series of cross-campus educational and research activities beginning in the summer of 2014 through the spring of 2015. The purpose of the Warfare Innovation Continuum is to provide a central theme that is relevant to the U.S. Navy, such as combat in the contested littorals, to students and faculty at the NPS for the purposes of studying utilizing the research and analysis tools unique to NPS within the DOD.

The central theme of this cross campus effort was to explore future methods of warfighting in contested littoral areas. Emerging technologies such as unmanned systems, laser weapons, and advanced computing and sensor capabilities provide the armed forces with future opportunities to fight effectively against sea denial forces in the complex and electromagnetically challenging littoral environment.

The SEA 21B team integrated our efforts with those of fellow students and faculty at the NPS in researching tactics, techniques, and procedures that will support U.S. military operations as a counter to the anti-access/ area denial (A2AD) strategies currently employed by U.S. adversaries in littoral areas around the world.

C. SYSTEMS ENGINEERING PROCESS

Systems engineering (SE) is a multi-disciplinary engineering field that uses the tools of systems thinking, business analysis, engineering, operations research, and modeling to advance the needs of project stakeholders from a simple idea representing a customer's need through to a functioning model of a potential system that answers that need. The general idea of the SE field is to map system development and sustainment directly to the needs of the customer in order to work out detailed system design before any system building actually begins. The ideas, wants, and requirements of the customer ultimately should manifest themselves into an end product system comprised of components that work in an effective and suitable manner to fulfill the customer's requirements.

1. Approach

The team's approach to implementing the SE process was to use an interactive, Waterfall-like process with recursive information loops that aided in the eventual formation of our team's tailored systems engineering process and preliminary system design. Figure 3 illustrates a textbook example of the Waterfall SE process that shows a full system life cycle starting with definition of a need all the way through system retirement and disposal (Blanchard 2008).

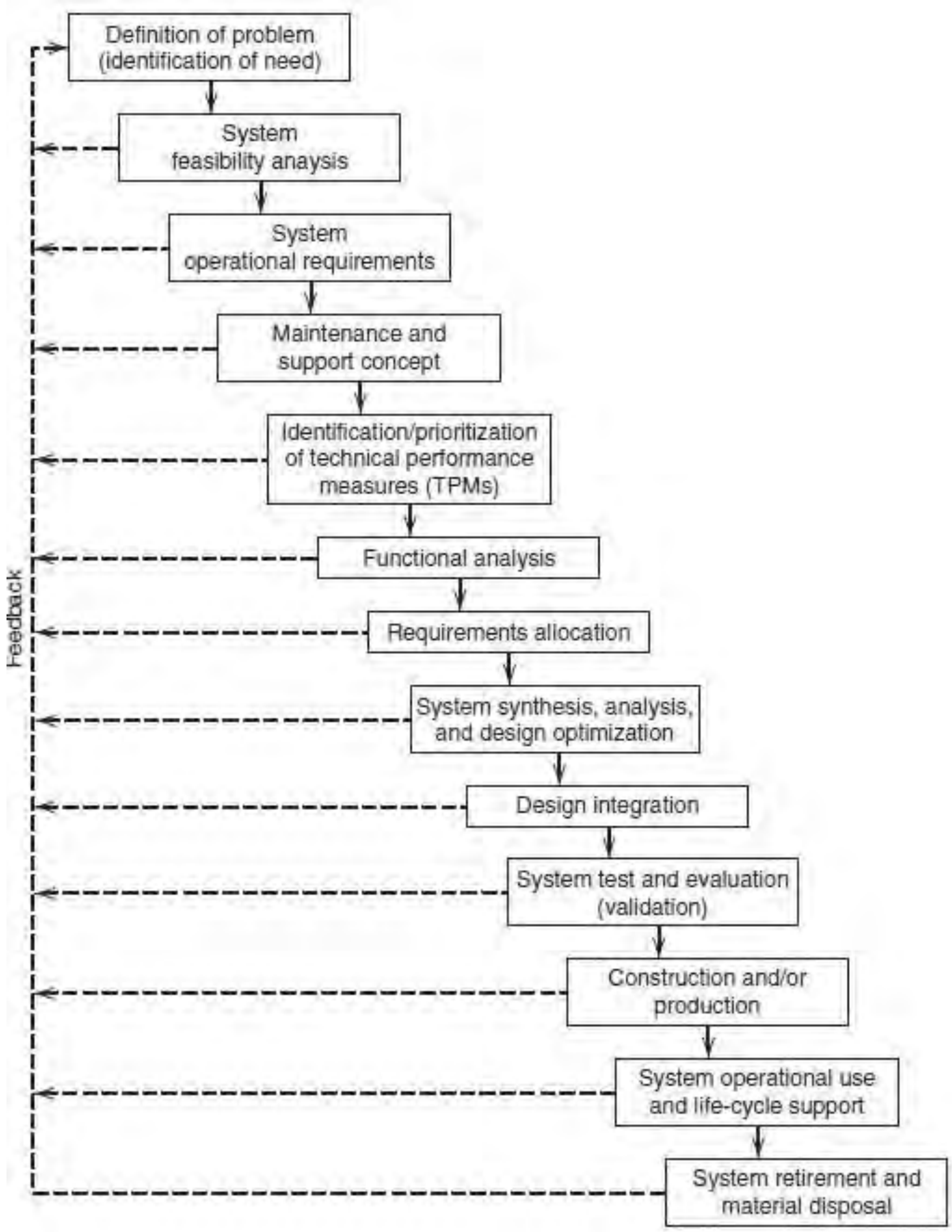

Figure 3. Systems Engineering Process (from Blanchard 2008)

2. Method

Many of the development steps shown in Figure 3 either did not apply to the scope of our tasking statement, or the steps we wanted to use were not detailed enough to guide our process. Based upon our team assessment, we decided that a combination of classical Waterfall processes shown in Figure 3 in combination with a tailored SE process specific to our team's focus and timeline would be a better fit to our team's structure and project design goals.

3. Tailored Systems Engineering Process

Figure 4 is the result of early team collaboration to select a process model we wanted to follow. Our model borrowed the three-quarter timeline design used by the previous year's cohort SEA 20B and replaced the internal steps with our team's specific design steps.

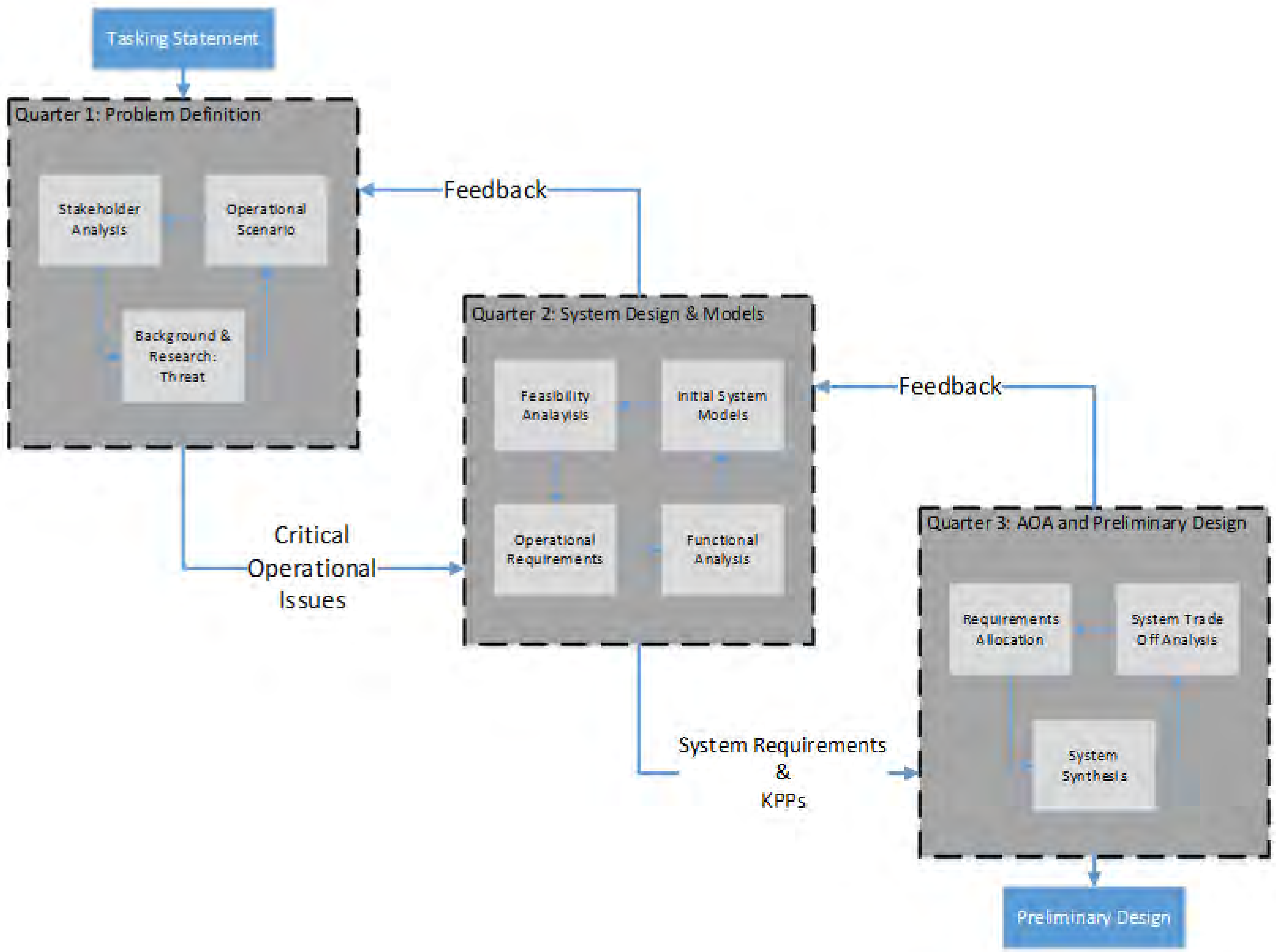

Figure 4. SEA 21B Tailored Systems Engineering Process

4. Quarter 1: Project Initiation and Problem Definition

The first step in the SE process is to define the problem being solved. Is there a problem? Can that problem be solved some other way outside of developing an entirely new system? The problem we faced had one advantage over a specific engineering design task in that we were tasked with composing a System of Systems (SOS) design concept and with identifying potential new system requirements or capability gaps within the DOD (Langford, 2014).

Applying the SE process as an approach to defining the problem allowed us to relate our project to the Joint Capabilities Integration and Development System (JCIDS) Capabilities-Based Assessment (CBA) in order to identify a material solution or a non-material solution that is based on changing one or some combination of existing Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P) systems. JCIDS' process is a DOD specific acquisitions process that supports the Joint Requirements Oversight Council (JROC) at the national strategic level. The primary purpose of the JCIDS is to help planners identify capability requirements of the warfighter and pair those requirements with performance criteria that then assist the JROC with the Planning, Programming, Budgeting and Execution (PPBE) Process from which the DOD defense budget originates. For our project, we focused on the first step of the JCIDS to produce a report similar to a CBA using our tailored SE process. According to the JCIDS, once a capability gap or change in the DOTMLPF-P is identified, it is then sent to the JROC to begin the planning process of the PPBE cycle.

The final product of our SE design project could serve as a standalone CBA that would result in one of the following:

a- A material solution resulting in an Initial Capabilities Document

b- A non-material solution resulting in a DOTMLPF-P Change Request

It was important to our team that we conducted our SE project in a way that reflects the realities of the DOD acquisitions process. The SE discipline plays a vital role throughout the JCIDS process and we reflected this need in our project. Stakeholder analysis, scenario development, and threat assessment are all related to defining the

problem statement. We began the process with the following three questions. What is the problem? Who has a stake in the problem? And what influence does an adversary have on our solution space? In Chapter II, we discuss these questions and our team findings in greater detail.

There were two major outputs from the first quarter's effort. The first was a refined problem statement agreed upon by the team and our stakeholders. The second was a list of Critical Operational Issues (COIs) our stakeholders felt were important. A COI is a concern stated in the form of a question asking fundamental questions about a system and its' nature in terms of operational suitability and operational effectiveness. Typically, only a positive response is acceptable for satisfying primary stakeholder concerns (DAU 2015). COIs and their associated measures are critical for system validation. Specifically, such questions should yield confidence that the SOS solution this team developed is suitable for the environment in which the SOS will operate, and that it will perform to a level that meets requirements. Each COI is evaluated via appropriate Measures of Effectiveness (MOEs) and Measures of Performance (MOPs). Langford (2012) states that an MOE is a system-level metric that compares the extent to which a function or process accomplishes a mission or task. In other words, effectiveness is determinable by what is appropriate and suitable, i.e., aligned with fitness for purpose, and not the desired outcome. Further, an MOP is the quantifiable actions of a function, as characterized by the performances of a function. In the following chapters, we will clarify the MOE and MOP concept as it applies to our system.

5. Quarter 2: System Design and Models

During Quarter 2 of the project, our team split into four groups. The first three groups focused on exploring the solution space in terms of a component of the DOD. We had our Navy, Marine, and Army & Air Force groups look at the requirements of the system and the functional decomposition of the system as it pertained to the mission found within the tasking statement we received. Each group created solutions based upon existing force structure and equipment organic to units within each DOD component. The

result of our team's effort is a refined list of system requirements along with a better definition of system Key Performance Parameters (KPPs).

6. Quarter 3: Analysis of Alternatives and Preliminary Design

During the last quarter of our team project we combined our four groups together and collaborated as a team to combine our system concepts and the models we would use later on to evaluate each system fairly against other system concepts within the team. The major undertaking during Quarter 3 was to develop each system concept and the MOEs and MOPs linked to each individual system into one standard set of systems and system measures. The resulting team product was the development of a system trade space our stakeholders and decision makers can utilize to evaluate potential system configurations based upon stakeholder need. The following chapters elaborate on the process our group used and the final product we created to answer our tasking statement.

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II. PRELIMINARY DESIGN: PROBLEM DEFINITION PROCESS

A. ORIGINAL TASKING STATEMENT

The original tasking was to design a fleet system of systems, concept of operations (CONOPS), and command and control to employ expeditionary assets in a range of missions to augment naval operations or conduct specified tasking in a contested littoral region in the 2025–2030 timeframe. We were to consider both manned and unmanned offensive and lift systems to execute missions of mine warfare (offensive and defensive) while facilitating raids upwards of company size. We were also to consider the capabilities of legacy systems and programmed systems to identify gaps and generate requirements. In addition, we were to evaluate the value of the architecture alternatives to larger campaign contributions, and assess the value of the adaptive mission package concept for inclusion in the alternative solutions. A caveat to this tasking was to consider only fleet forces and structures that currently exist or are already under development. We were then to use those timeframe considerations as a baseline for generating capability gaps, requirements, and a CONOPS. Alternative architectures were also deemed necessary for evaluation of platform and manning requirements, command, control, communications, computers, and intelligence (C4I), as well as procedures for operational use. Finally, we were to address the costs and effectiveness of each of the alternatives.

From the beginning of the project, there was a healthy disagreement amongst the team members as to what direction to move forward with the project. In order to resolve any debate on where to take the project our team worked through interpreting the original tasking statement utilizing the SE process to help redefine the problem in such a manner that both the team and project stakeholders could agree on a final project end state. The following sections described how our team was able to accomplish this first step in the SE process.

B. STAKEHOLDER ANALYSIS

In considering the problem of conducting expeditionary operations under an A2AD threat, all aspects of expeditionary operations must be considered, and a multitude of stakeholders come into play.

1. Key Stakeholders Identified

If the problem as proposed thus far in conducting an amphibious raid is considered from the perspective of the Navy, then the stakeholders outlined below are limited to Navy representatives. Primary stakeholders address the issues that are most relevant to the aim of this study. The secondary stakeholders listed below were found to be representatives or organizations who were able to provide valuable input to the investigative process of this thesis report, and whose responsibilities were aligned with question posed by this document.

Primary Stakeholders

- Mr. Bob Novak, Deputy N9I
- Professor Jeff Kline, CAPT (Ret), Systems Engineering Analysis Chair
- Dr. Gary Langford, Advisor
- SEA 21B Team

Secondary

- Rick Williams, RADM (Ret), Mine and Expeditionary Warfare Chair
- Jerry Ellis, RADM (Ret), Undersea Warfare Chair
- NPS Faculty
- LCS Squadron 1

2. Stakeholder Primitive Need Identification

Table 2 provides a summary of each stakeholder's primary concerns.

Table 2. Primitive Stakeholder Needs

Stakeholder	Needs
Mr. Bob Novak, Deputy N9I	Capability gap analysis, preliminary analysis

Stakeholder	Needs
Professor Jeff Kline, CAPT (Ret), SEA Chair	Capability gap analysis, cohort completion of capstone project, viable recommendations to N9I
Dr. Gary Langford, Advisor	Cohort completion of capstone project, quality educational experience for the team, viable recommendations to N9I
SEA 21B Team	Capstone project completion and follow on graduation
Rick Williams, RADM (Ret), Mine and EXWAR Chair	Insight and preliminary analysis of the future of expeditionary operations, viable recommendations to N9I
Jerry Ellis, RADM (Ret), USW Chair	Insight into the potential impact and implications of the future USW environment with regard to expeditionary operations in the contested littorals
NPS Faculty	Innovation for use in further research
LCSRON 1	Feasible, realistic options for tactical employment of LCS

3. Stakeholder Interviews and Information Collected

Numerous stakeholders were engaged to obtain insight that could feed into project requirements. The information obtained from these discussions can be broadly divided into structural, operational, and technological categories. However, some information easily fits into these multiple categories.

4. Original Problem Statement Feedback

Stakeholders expressed a common need for clarification of the original problem statement and the meanings of multiple terms used in it. This included determining the purpose of the company-sized raid in relation to the rest of the statement. Other needs expressed by at least one of the primary stakeholders included clearly defining a scope for the solution. We assume that a target island is either uninhabited or that a friendly nation has invited our forces to its inhabited island.

a. Information Sharing

Stakeholder requirements for shared operational related information included:

(1) The need to get to the desired location prior to the enemy was repeatedly emphasized. This emphasis on the need to arrive first fed into scoping the problem in such a way that friendly forces were not expected to have to fight their way ashore. This insight correlates to the fact that blue forces are invited by the host nation.

(2) Successful system employment requires host nation “buy-in” to the operation, and the need for their support in terms of basing and troops. If a nation wants our help in defending their islands then they need to facilitate the system’s employment by providing pre-staging locations as well as cultural acclimatization.

(3) Small, fast ships must be part of the solution vice more expensive ships. While these smaller ships are less capable they also have the following benefits: lower cost, higher stealth, and lower desirability as targets.

(4) Potential landing sights are highly varied. They include islands with modern infrastructure including airfields and paved roads all the way to atolls that might not always be above water.

(5) While the landing force would not have to fight their way onto the island, they would need to be able to present a viable deterrent in order to mitigate the chance of an enemy invasion or counter-attack.

(6) The landing force and their delivery vessels could not be the primary defensive force. The system would need to be protected by an umbrella of joint assets in order to provide defense against the full threat spectrum. Any attempt to make the landing force the sole defense would result in a rapid increase to personnel and supply requirements.

(7) Landing forces must be supplied in such a way that the effects of a surface blockade can be negated.

Do not underestimate the difficulties Red forces could face in this problem. This notion is especially relevant in a South China Sea scenario. Particularly, Red forces may have difficulty with maintaining supply lines, deterrence provided by the presence of blue forces, and political difficulties related to the risks of removing blue forces from an island (risking escalation to a kinetic conflict).

(8) Water and fuel for electrical generation are the primary supply items. Decreasing requirements for both result in a less vulnerable supply chain.

b. Impact of Technology

Common technological themes included:

(1) An island surrounded by sea mines could pose a significant threat to surface platforms and operational success. However, standard mine clearance techniques would be detrimental to the requirement to get to the

location first. Rapid mine clearance and other unconventional techniques would be required in order to counter a mine threat while meeting that requirement.

(2) Speed of initial delivery would have to be augmented by speed of resupply in order to counter a possible enemy blockade. As such, high speed surface vessels could be used to deliver a large initial amount of supplies in order to mitigate the initial effects of a blockade. Precision air drop could be used to maintain stockpiles for the duration of the blockade.

(3) Organic defense systems would need to be capable of rapid deployment, operations and maintenance by a minimal number of personnel, and integration into the Joint command & control system.

(4) There are numerous unmanned systems that can be deployed as part of the system. These systems have the benefit of augmenting organic ISR and defense capabilities far beyond those of a typical rifle company. However, these systems induce added requirements for maintenance, supply, and communications.

C. REFINING THE PROBLEM STATEMENT

1. Scoping the Problem

Following stakeholder analysis and conducting a thorough review of the original problem statement, the team decided that some revisions were necessary to refine the original problem statement. A refined problem statement would help focus the problem more on stakeholder needs and provide a manageable challenge to the project group. The presented problem statement, in general, was very large in scope and presented many challenges that required more time and resources for assessment than were available to our project team. Establishing baseline assumptions, the team was able to determine the in-scope and out-of-scope details for this project.

a. In-Scope Assumptions

Retains expeditionary (read: “amphibious”) operations as the main tasking for the project. The reason for this focus is because the Marine Corps currently are not accustomed to operating at the company level.

b. Out-of-Scope Assumptions

The mine warfare aspect of the original tasking for the purpose of this project is considered to be out of scope. During functional decomposition our group discovered that focusing on mine warfare distracted from the greater overall problem statement given to our team. Our team defined mines as a condition. A belligerent either possesses mines or it does not possess mines. The project group wanted to focus on an area that has yet to be addressed and therefore we did not impose this condition on the report. A secondary reason for excluding mine warfare from our study is because mines were recently evaluated in a NPS Thesis (Frank 2014)

The scenarios for this project are un-imposed amphibious landings of uninhabited islands. Any type of opposed landing would be considered to be out of scope and consistent with current United States military amphibious landing doctrine.

2. The Refined Problem Statement

Based on the feedback received from stakeholders, the team added depth to key elements while eliminating other elements from the original tasking statement. In this way we established the scope of our problem and solutions. We maintained that we would design a fleet system of systems, as well as its CONOPS, force package levels, and command and control to deploy and support company-sized, rapid response expeditionary assets in a contested littoral region in the 2025–2030 timeframe. Keeping the originally tasked timeframe meant also incorporating only joint platforms that already exist or are in funded development with initial operating capability within a few years. The team decided that capabilities, requirements, CONOPS, and alternatives for each, along with the manning and C4I, all of which were necessitated by the original tasking were still items to complete. We added the need to incorporate manned and unmanned offensive, as well as transport, systems to execute any necessary missions or neutralize potential threats. We included an evaluation of the value, cost, and effectiveness of our architecture and alternatives as applies to larger campaigns, including an assessment of the value of an adaptive mission package concept in our alternatives.

a. Effective Need Statement

The question, "How do we conduct over-the-horizon (OTH) amphibious operations in an A2AD environment at a company sized level?" drives the team's effective need statement: A joint system-of-systems is required to conduct company sized expeditionary operations in an A2AD environment.

b. N9I Brief and Problem Statement Approval

On November 18, 2014, the Office of the Chief of Naval Operations N9I Deputy Director visited Naval Postgraduate School to receive briefs on progress that the System Engineering Analysis 21 cohorts had made to date. This visit was the first opportunity for SEA 21B to brief a primary stakeholder on their problem statement redefinition and planned way forward. The resulting feedback from the brief was positive and confirmed the direction that the project team would head in the future.

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III. BACKGROUND AND RESEARCH

A. HISTORY OF THE SOUTH CHINA SEA

1. Historical Claims

The South China Sea is an area rich in history of trade relations between the nations of Southeastern Asia and the archipelagic nations of the Southwestern Pacific Ocean. The region's history also includes multitudes of mainland conquests and control shifts between historical dynastic empires. Some of these empires, particularly that of Japan in the 1930s and 1940s sought to assert control of the regional maritime domain as well. The Spratly Islands, shown in Figure 5, are located far to the south of what is now China and Taiwan, southwest of Japan, west of the Philippines, north of both East Malaysia and Brunei, and east of Vietnam. In what can only be described as a maritime crossroads, outright control of some or all of the Spratly Islands has been pursued by all of its neighbors, with no indigenous population to claim sovereignty as a group of islands. More than just for trade route interests, the Spratly Islands have been identified as a likely source of a wealth of oil and natural gas resources to fuel future hydrocarbon needs.

Figure 5 shows not only the proximity of the islands to some of the surrounding nations, but also illustrates the waters claimed by many of the parties involved. Of particular interest is China, who claims the zone outlined in red as a part of their historical "9-dash line" claim circa 1953, which was derived from a strategically mapped 11-dashed line idealized by Chiang Kai-Shek during the era of the Second World War (Malik 2013).Vietnam in particular disputes that China has any right to claim maritime domain other than the coastal waters immediately adjacent to its mainland and Hainan Island (BBC 2015). In spite of these disputes over precedent, The United Nations Convention on the Law of Sea, of which China (regrettably it seems) is a signatory, specifically rejects historical claims (Malik 2013).

Figure 5. 9-Dash Line Zone and UNCLOS (from BBC 2015)

2. Present-Day Disputes

In recent decades there have been multiple incidents where inflammatory rhetoric has escalated to isolated armed conflicts. These small-scale violent events have primarily occurred in the form of naval standoffs between China and Vietnam or between China and the Philippines. The following are examples, all eight bullets points listed below are as quoted from "Dispute 2015" in the reference list:

- In 1974 the Chinese seized the Paracels from Vietnam, killing more than 70 Vietnamese troops.
- In 1988 the two sides clashed in the Spratlys, with Vietnam again coming off worse, losing about 60 sailors.
- In early 2012, China and the Philippines engaged in a lengthy maritime stand-off, accusing each other of intrusions in the Scarborough Shoal.

- In July 2012, China angered Vietnam and the Philippines when it formally created Sansha city, an administrative body with its headquarters in the Paracels, which it says oversees Chinese territory in the South China Sea.
- Unverified claims that the Chinese navy sabotaged two Vietnamese exploration operations in late 2012 led to **large anti-China protests** on Vietnam's streets.
- In January 2013, Manila said it was taking China to a UN tribunal under the auspices of the UN Convention on the Laws of the Sea, to challenge its claims.
- In May 2014, the introduction by China of a drilling rig into waters near the Paracel Islands led to multiple collisions between Vietnamese and Chinese ships.
- In April 2015, satellite images showed China building an airstrip on reclaimed land in the Spratlys. (all bullet points from "BBC" 2015)

3. Potential Conflicts

China's unprecedented industrial growth since the mid-twentieth century has afforded it not only an enhanced voice in global affairs, but also a regional hegemony from a military if not an economic perspective. Though many of the smaller nations who contest China's claim to the disputed areas in the South China Sea (particularly the Spratly Islands) have called for multi-lateral boundary negotiations, China has insisted on strictly bilateral talks. This stance allows them to presumably bully the contestant nations individually, while demanding that potential power brokers like the United States avoid involvement. Attempts to resolve maritime disputes via U.S. mediation or the World Court's International Tribunal have met in some cases with utter outrage from senior Chinese officials (BBC 2015). They seem to view such efforts as intervention from entities that have no stake, but fail to acknowledge the objective viewpoint that such measures can provide to a passionately volatile situation. Regardless, any ruling from external agents is not obligatory for China, so as it continues to assert its claims through island-building efforts, the potential for armed conflicts with other claimant nations continues to grow.

Southwest of China's Nine-Dash Line's limits lies the Natuna archipelago; part of the Riau Islands and sovereign territory of Indonesia. The island of Natuna Besar (or Greater Natuna), has an area of 1720 square kilometers (Brandon-Jones 2004) and is strategically located such that it could potentially grant China an enormously large

staging point for continuous, expanded military operations to assert dominance of the South China Sea areas it lays claim to (see Figure 5, an island halfway between mainland Malaysia and Brunei). This island provides an important possibility for the SEA 21B team to explore, which is the feasibility and consequences of implementing our theories in a populated environment.

B. RED GROUP ANALYSIS

Opposition force research was focused on what the group assessed to be the worst case scenario: China. A near-peer competitor with the United States armed forces, China is particularly worth assessing as a potential adversary for the team's tasking, especially given the possibility of future conflict with allies of the United States. Further research delved into capabilities that other possible adversaries could leverage, but the focus of opposition modeling revolved around Chinese forces.

This assessment had four components:

1. Red force assumptions
2. Red force capability assessment
3. Red force most feasible tactics
4. Red force most feasible force package

The Red group relied on a number of assumptions for the analysis of Red forces. Firstly, Red forces were prepared for the scenario, with ample time for pre-scenario actions (planning, consecration of forces, exercises and more) but with low-signature or in decoy, such that Blue forces were afforded the shortest possible reaction time. The assumption from these considerations was that the evident actions will be six hours prior to H-Hour. Secondly, Red forces were not able to use any Weapons of Mass Destruction throughout all of the various scenarios. Thirdly, Red forces maintained a surface screen for the purpose of local sea control around the target island at every opportunity. Red forces assumed any Blue forces or threats of force were valid. Finally, Red forces made every effort to prevent entry access to any military or civilian entity attempting to penetrate local sea or air space within the blockaded "sanitation zone," even in the case of inhabited islands.

1. Assessment

a. Capabilities

The Red force capability assessment was based on a report by the Congressional Research Service: "China Naval Modernization: Implications for U.S. Navy capabilities - Background and Issues for Congress" by Ronald O'Rourke. The report highlighted four main points:

(1) The Chinese Navy is having an accelerated modernization effort, which started at the beginning of the 1990s.

(2) The Chinese Navy is focused on improving the quality more than quantity. This is the reason we could try and forecast the amount of Chinese naval assets. The full list of current and forecast Chinese assets can be located in Appendix E.

(3) The DF-21 (a theater-range ballistic missile equipped which designed to hit moving ships at sea (O'Rourke 2014, 5)) which the Chinese are developing and testing at is a "game changing" weapon, because of their high accuracy which can presumably hit aircraft carriers and other high-value assets, in addition to their range and maneuverability which makes them hard to intercept. The DF-21 is a major component in the Chinese ability to create A2AD environment.

(4) The Chinese are planning to expand their aircraft carrier fleet, and under the currents plan, they will have a total of three operational by the project's scoped time frame. Employment of that force is assumed to be in that of battle groups similar to U.S. doctrine, but divided into their own theatres of interest.

b. Limitations

Here are the major limitations that the report claims about the Chinese capabilities that could affect the blue force efforts. It is important to mention that in the 10–15 years between this release and the scoped time frame, some (and maybe all) of the identified capability gaps could be closed by the Chinese:

(1) Carrier-based aircraft, the J-15, is limited to air-superiority and ship-defense rolled only. They lack air-offence capability due to carrier limitations.

(2) The Chinese Marines to this point have never conducted a division-scale amphibious warfare exercise. They have limited joint operations with other services of the People's Liberation Army (PLA).

(3) The Chinese submarines are not currently as stealthy as the United States Navy (USN) submarines. Because of that, they are largely limited to a coastal defense role. There is a low probability that the submarines will be used as access denial enforcing system.

(4) The Chinese has a dependency on Russia for military-grade technologies and some critical spare parts.

(5) The People's Liberation Army Navy has not undertaken a large-scale or long-range amphibious operation in modern times. Furthermore, the PLAN has had no recent experience with the massive logistical infrastructure required to support such an operation, and also lacks experience in operating in a joint or integrated fashion, which is a prerequisite when facing a modern, peer adversary. The United States, in contrast, has very recent logistics experience in supporting overseas operations due to its activities in Afghanistan and Iraq. Additionally, the U.S. pioneered joint air, land, and sea operations, and maintains high training standards for amphibious operations as a matter of routine. This lack of operational experience on behalf of the Chinese provides some incentive for them to avoid direct, armed conflict with the United States.

2. Other Adversaries and Emerging Technologies

As stated before, our study's main adversary was the Chinese military, especially the Chinese Navy. In order to be complete, and to be prepared for all of the scenarios, we conducted a research on additional threats other adversaries can impose on the USN. Our goal is not to create a comprehensive list of adversaries' capabilities, but to identify the "game changing" assets and technologies.

We also researched emerging technologies that can be developed and adopted by any adversary that can be part of this scenario.

(1) Russia

Russia has much stealthier and more sophisticated submarines than the Chinese. For example, Russia launched in 2014 a new Kilo-class submarine for the black-sea fleet ("Russia" 2014). There is evidence that a Russian submarine (although not a littoral type) has sailed in the Gulf of Mexico without detection by the USN (Gertz 2012).

The Kilo-Class submarine can be a high threat blockade assets, because their ability to operate in the littoral, as a stealthy threat which prevent the USN approaching the island, without knowing where the threat is located.

(2) North Korea

North Korea Intercontinental Ballistic Missile capabilities, which includes the Nodong (1,000 Km range), the Taepodong-1 (2,200Km range), the Musudan (4,000 Km range), and the Taepodong-2 (6,000 Km range) can impose a severe threat on United States forces and allies in the East-Asia region, as a means of effecting a blockade (“BBC” 2013).

3. Technological Improvements and Plausible Alternatives for Red Group Assets (Based on 2025–2030 Timeframe)

Based on the capabilities presented by both North Korea and Russia, swift launching of assets in a first-strike environment could lead to a swift and decisive victory for either party. The various technology improvements that could possibly evolve into viable future weaponry include the following:

(1) High-Powered Microwave

This technology could potentially disrupt the Blue Force’s communications and electronics assets; and often, the Blue Force would not be able to discover them. A high-powered microwave can be disguised by embedding the system(s) into locations such as shipping containers or even large cavities like well decks or cargo holds.

(2) High Energy Laser

Cost effective and highly lethal, these laser weapons can potentially destroy or degrade armaments or aircraft bodies in the skies, disrupting friendly aerial assets from ingress into the area of operations (OPAREA).

(3) UAV Swarm

These minute flying machines can be left unmanned once launched, and upon doing so be deployed near the Blue Force’s OPAREA for maximum disruption. The drones to be used for swarming are relatively inexpensive and payloads can be added to cause even more mayhem in deployed locations.

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IV. SCENARIO DEVELOPMENT PROCESS

A. OPERATIONAL SCENARIOS

In framing our approach to the approved problem statement, it was important to create a narrative framework that would help scope and define the specifics of our tasking. The first step in creating a narrative was to generalize the potential scenarios with a series of assumptions or factors derived from the problem statement. This statement specified that our workspace must include an A2AD environment and should focus on rapid company-sized amphibious troop deployments. From there, we made the assumption that our efforts should be aimed at a near peer adversary capable of deploying A2AD measures in a littoral or amphibious region. Finally, considering the inherent limitations of a company of Marines or soldiers as well as the implications behind a "rapid" deployment, we decided our goal would be to place a company of troops on an island within a specific time frame. Essentially we would be "racing" an adversary to an island and, if our troops arrived first, that would be assumed as a sufficient deterrent to the adversary contesting American control of the island(s). In crafting a narrative, it would be easy to stack the cards in favor of the United States, but this would not generate any worthwhile results from our study and so we, rather than create an easy or overly "realistic" scenario, focused on developing a worst-case possibility.

1. Scenario 1: The Baltic Sea

Our first scenario took place in the Baltic Sea. In this narrative the United States received intelligence indicating Russia plans to seize Gotland, a Swedish island with a strategically valuable location in the Baltic. Analysts believe that Russians are not willing to go to war with the United States or the North Atlantic Treaty Organization (NATO) over this island and so, if there was an increased troop presence, this would deter Russian aggression. The Swedish government has requested a NATO exercise on Gotland and the United States has agreed to deploy a company of Marines in a show of force. These Marines will augment Sweden's own Amphibious Corps (the coastal

defense branch of the Swedish Navy) and must arrive on the island within twenty-four hours, with a target time of eighteen hours.

This scenario provided a rough framework, but lacked the challenge of other geographic areas. The forward-deployed American units and equipment in Europe as well as the existing NATO infrastructure and capabilities of other NATO nations removed much of the challenge that American forces would otherwise face. Thus, although useful in framing the problem, this scenario was determined to not be our primary focus. Any data or system utilized in our solution would be applicable to this scenario; it simply was not designed with it specifically in mind.

2. Scenario 2: South China Sea Race to the Spratlys

With the lessons of Scenario 1 in mind, we selected a region that posed a greater challenge to American lift capabilities for our next scenario—the South China Sea. Considering our timeline of ten to fifteen years in the future, it is reasonable to assume that the People's Republic of China will continue its economic and military growth at, at least, its current rate. Thus, by 2025, China will represent a near-peer adversary threat to the United States. Couple this power with the fact that China is a pioneer of the A2AD strategy and has several territorial disputes with American allies, and the South China Sea became a clear choice as a potential "worst-case" scenario.

Following the framework of Scenario 1, Scenario 2 begins with the United States receiving intelligence that China has plans to seize an island, this time in the Spratly Island chain. The Spratly Islands consist of more than one hundred land formations spread across 410,000 square kilometers of the South China Sea. Combined, the total landmass of the islands is less than five square kilometers of harsh rock and sand, yet an estimated $5 trillion in maritime trade passes through the chain each year ("Sea" 2012). Between its allies' interest and territorial claims in the region and the potential economic disruption if trade were to be halted or re-routed, the American government is certainly concerned with any changes to the islands' current status quo.

With this in mind, Scenario 2 tasks the United States with placing a company of Marines or soldiers on the designated island in the Spratlys faster than China can get its

own troops to it. The company would be assumed to be a forward-deployed "ready" company that could deploy on short notice utilizing Navy and Air Force assets in the region. Although speed of deployment would obviously be an important metric in this situation, additional concerns are the visibility (or detectability) of the deployment system and the amount of lift capacity it has for troops and materiel.

Although this narrative was objectively improved over that of Scenario 1, in that it would better stress American capabilities, this scenario proved difficult in other ways. First, is there an island with large enough above-sea surface area in the Spratly chain on which to garrison an entire company? What equipment would the company of Marines or soldiers have with them? How do we quantify "beating" the Chinese to the island without being presumptuous regarding their ability to embark troops, which bases they would operate out of, and their potential speeds of advance? We addressed the first question by assuming an island big enough to accommodate whatever number of personnel and equipment we chose to land. The consequence of this assumption is that both the Chinese and the Americans will only land on the same minimum square footage. This is an important step in ensuring our solution translates to any geographic region, and not just the space-constrained South China Sea. The other questions, however, were not so easily addressed and so we chose to evolve the narrative further.

3. Scenario 3: Expanding Our Own A2AD Envelope

For our third scenario, we explored another South China Sea narrative, but with a very different framework. Considering the People's Republic of China already occupies several islands in the Spratly chain and is actively working to grow the landmasses its troops already reside on, it makes little sense to focus on beating the Chinese to another island in the chain. Winning such a race would perhaps provide little strategic gain for the United States and losing would provide little loss for China. Thus, we sought to create a more realistic scenario that would help drive more useful requirements for our system.

As a solution, we looked at a potential political shift in the Pacific where China installs its A2AD technology on its outposts in the Spratly Islands and then declares the archipelago closed to international maritime traffic. Such a scenario would be

devastating to the international economy and would absolutely draw a swift response from the United States. Furthermore, given the U.S. Navy's tradition of conducting Freedom of Navigation missions, this is a scenario easily understood by American policy makers.

In this scenario, the United States makes the decision to land a company of Marines on an outlying island in the Spratly chain with the means of securing the nearby sea lines of communication. This company, or follow-on companies, will be "leapfrogged" across the uninhabited islands of the Spratlys in an effort to provide the United States with its own A2AD "bubble" that will protect merchant and military shipping and deter Chinese aggression. However, due to the existing anti-ship cruise missile (ASCM) and submarine threat to large surface combatants and amphibious assault ships, the United States will not utilize a conventional amphibious landing to accomplish the insertion. The desire is, instead, to develop a system of systems that utilizes low-cost, A2AD-survivable platforms in an effort to minimize the potential loss of a large ship costing billions of dollars and holding thousands of lives. Due to the potential risk of operating within the Spratly Island chain in this scenario, it would be unlikely that the insertion platforms would remain in the vicinity of the islands and thus the company of Marines must be self-sufficient and capable of providing a reasonable deterrent to threats from the surface or the air.

This scenario provided the clearest framework for developing requirements and drove our creation of three service-based groups: a Navy group, a Marine group, and a joint Army-Air Force group. These groups were focused on different parts of the assignment, with the Navy group focusing on delivering the Marines inside of the A2AD environment, and the Marine group focusing on developing a series of specialized, self-sufficient platoon-sized force packages, each with a specific mission in mind. The Army-Air Force group focused on aerial delivery and the creation of Army-based force packages.

In short, our final scenario met all the requirements laid out in the assigned mission statement. The economic and military ramifications of losing access to the waters surrounding the Spratly Islands (and therefore many ports around the South China

Sea) would prompt an immediate response by the United States. The threat posed by A2AD weapons would rule out traditional amphibious operations and thus prompt the creation of a new system. It would need to be rapidly deployable, reliable, roughly the size of a single company, and would need to be capable of self-sustainment in an A2AD environment. Furthermore, the deployment capabilities and various force packages would all be easily translated to any other geographic theater. The ability of a company of Marines to unilaterally provide a “bubble” of sea and/or air control in addition to their possession of the land itself, could provide military decision makers with a host of new, flexible options in future conflicts. The ability to rapidly deploy and sustain such a company with minimal platform dedication is just another major benefit.

B. RED FORCE SCENARIO

Red forces are best assessed by making assumptions about the nation in question. This discussion is best accomplished by examining the options available and determining a most likely COA, to include movements and tactics.

1. Possible Red Force Ingress

The analysis is done for both air ingress and sea ingress scenarios, and the conclusion is that the Red group possesses the capabilities to stage an earlier ingress into the OPAREA, provided that they could launch air assets from nearby islands. One of the islands in contention for such a scenario is the Paracel Islands, which include assets as significant as a full length runway for fast and efficient launching of Red force aircraft. Figure 6 shows a detailed map of routes.

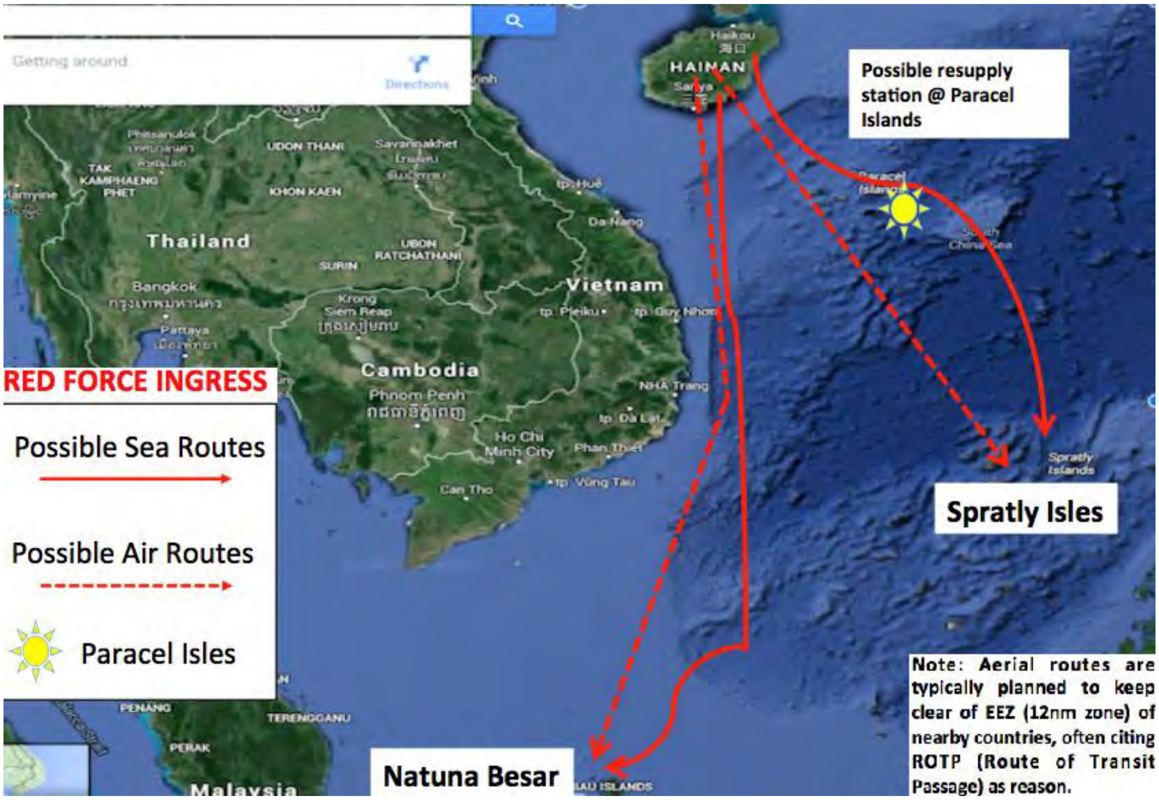

Figure 6. Red Force Ingress Options (after Google 2015)

2. Possible Red Force Tactics

As a primary means of disrupting Blue Force's shallow water tactics, the Red force can utilize an array of anti-ship missiles. This arsenal may include Anti-Ship Ballistic Missiles (ASBM) and ASCMs. If the Blue force instead opts for fixed or rotary wing airborne insertion of troops, the Red force possesses anti-aircraft missiles, and Man-Portable Air Defenses (MANPAD). This arsenal may even include the FN-6, a 3rd-generation passive IR MANPAD that is designed specifically for targeting low-level aircraft.

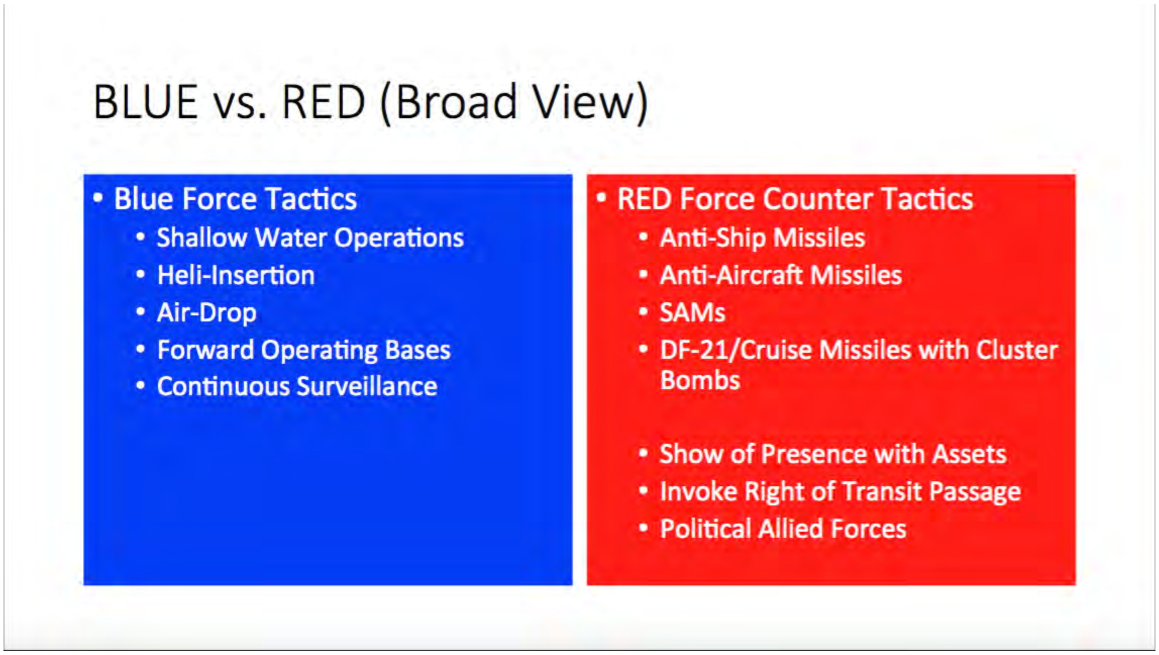

Figure 7. Red Force Tactical Assessment

3. Red Force Deployment

Based on the current Red force's asset availability, an assessment is required for the most likely order-of-battle in the contested region as a counterforce to the Blue force. A primary assumption for these scenarios is that the Red force deploys a force package similar to that employed by the Blue Force. Table 3 illustrates the estimated force package that the Red force would make available for the contested littorals.

Table 3. Red Force Mission Package

Assets	**Type**	**Quantity**	**Remarks**
PLAN Marine Corps	Ground Troops	200	Includes supporting equipment
Amphibious Landing Ship	072	1	Includes 4x Z-8 Super Frelon Rotary-wing aircraft
Missile Boat	022	8	Small Combatant Ship
Destroyer	052C	4	Aircraft Carrier Escort
Aircraft Carrier	Varyag-Class	1	
Strike Aircraft	J-15	10	Carrier-Based
Mine Countermeasure	081	1	
Anti-Ship Ballistic Missile (ASBM)	DF-21	1	Launched from mainland

Two destroyers and two frigates are included into the list of deployable assets as the Aircraft Carrier escorts. Missile assets such as the DF-21 ASBM can be deployed and launched from within the confines of their country; hence, these assets will not be brought to the contested littorals. Nevertheless, they are also included in Table 3 to indicate overall type and quantity of assets that is involved in the Red group's force package. The deployable assets discussed in Appendix B provide the necessary infrastructures and launch-platforms for the aforementioned Red force tactics.

V. SYSTEM OPERATIONAL REQUIREMENTS

A. SYSTEM REQUIREMENTS TRACEABILITY

The process of defining system requirements and ensuring traceability between a stakeholder and a system component is a fundamental, and recursive, step within the SE process. The requirements traceability process begins with analyzing who the stakeholders are and also analyzing what stakeholders individually and collectively view as important. In the case of DOD stakeholders, the concept of COIs helps with identifying fundamental system requirements. COIs do this by posing questions about operational effectiveness and operational suitability ("DAU" 2015). COIs are best used phrased as a question made by the stakeholder. In the case of our system, the stakeholder COIs our team developed were the following;

COI 1: DEPLOYABLE: Can we beat the adversary to an island with our system?

COI 2: SUSTAINABLE: Can we deliver initial troops and supplies?

COI 3: DEFENDABLE: Can we defend the island?

COI 4: RELIABLE: Can we use this system on short notice?

COI 5: AFFORDABLE: Can we afford the system?

1. Stakeholder to Component Traceability

The COIs listed above reflect our team's collective effort to represent concerns about stakeholder requirements. In this case, our team chose to assign a stakeholder role to each of the DOD service components. As a result, relationships between stakeholders and COIs formed a branching effect that resulted in some stakeholders having multiple COIs. Under such a paradigm, each COI could result in multiple operational requirements that in turn could each lead to multiple system requirements.

Figure 8 shows the relationship between the high level needs off the stakeholders traced to the many system components comprising a system and the respective MOEs and MOPs utilized to evaluate the system.

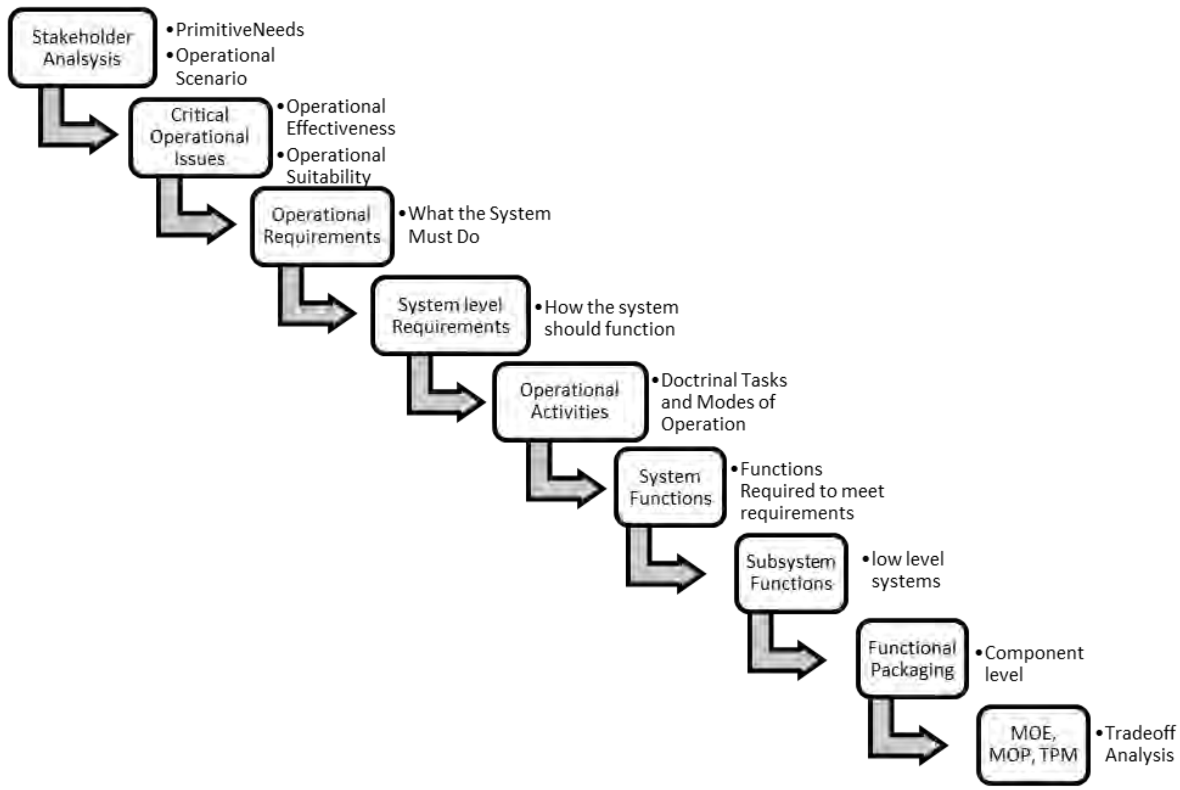

Figure 8. Stakeholder to System Models Traceability

Traceability helps to ensure that every requirement is addressed within a system design. For every stakeholder requirement there needs to be a corollary component, or collection of components, within the system that serve to meet that stakeholders' stated need. Likewise, for every stakeholder requirement there needs to be a validation process using MOEs and MOPs where the effectiveness and performance of the system is evaluated ("DAU" 2015). This process yields a result where every physical component comprising a system is designed and made for a specific purpose within the completed system that supports a stakeholder requirement.

B. STAKEHOLDER CRITICAL OPERATIONAL ISSUES

To begin the design process our team needed to clearly define the stakeholders' COIs and in what way those COIs would influence our team's design decisions. The following section elaborates on each COI and describes how our team understood the impact those COIs on our system design.

1. COI 1: Can We Beat the Adversary to an Island with Our System?

COI 1 asks a fundamental system design question about operational suitability and operational effectiveness. In order for or our system to be effective at deterring adversaries from seizing islands in an A2AD environment the system must allow our forces to move to a specific geographic location first. As mentioned in the scenario, the advantage goes to the first force able to land on an island first. Beating an adversary to an island is ultimately a race between two competitors to see who can reach an advantageous position first. The first force that is able to arrive at an island first can then claim that island as rightfully theirs. As a result, the first force to an island is able to establish a defensive occupying force.

Defensive forces hold a numerical advantage over attacking forces in the classical 3:1 ratio where there is a requirement for 3 attackers for every 1 defender to reach parity in combat strength. The 3:1 combat ratio is a traditional force planning measure used by the U.S. Army and Marine Corps to assist in planning for force requirements. The 3:1 combat ratio makes actual combat unlikely in our scenario because the risk of escalation is too great. The later arriving force would then need to bring a minimum of 3 times the defending force's number in order to conduct an in opposed amphibious landing onto an occupied island. Opposed amphibious landings are inherently dangerous and require the attacker to invest more in resources along with the possible escalation of tensions at the strategic level. Therefore, the force ratio advantage goes to the force that is able to occupy a contested island area first. The capability of arriving at a contested island first provides two important advantages to an amphibious landing force. The first advantage is that landing on an unopposed beachhead places the fastest force in a position of an occupying defending force. The second advantage is that the force can be small initially

in an unopposed landing scenario. Hence, it is vitally important that our system allows us to deploy to a disputed territory before our enemy deploys his forces.

2. COI 2: Can We Deliver Initial Troops and Supplies?

COI 2 asks a question about system suitability. Is this system suitable for the intended mission and operating environment? Our stakeholders require that the system delivers small units to amphibious areas in contested littoral regions. Given the timeframe of 2025–2030 our team determined that small units in the Marines and Army would remain primarily manned versus unmanned. That is to say, the primary fighting instrument our system would incorporate would remain the combat infantryman. Making this assumption opened up volumes of doctrinal information on Infantry combat loads, consumption rates, fighting capability, and other various forms of data that are readily available as combat proven information. This assumption did not preclude the use of unmanned systems augmenting future small units with additional capability. The Infantry fighting force at the small unit level would be a base case to make assumptions on in order for us to begin working our system designs and models.

3. COI 3: Can We Defend the System in an A2AD Environment?

One of the primary concerns in manned systems is the ability to defend against enemy attack. COI 3 is a question of system operational effectiveness. How effective is the system at deterring aggressive enemy action towards itself? And once the system is operating within the boundaries of an A2AD environment can the system protect itself against outside threats? Our team determined that the system needed to possess some level of lethality in order for the system to pose a credible force against the most probable adversarial threats.

4. COI 4: Is the System Reliable?

An early system Key Performance Parameter (KPP) that our group determined as essential for system success was speed. A KPP is defined as a, "Performance attribute of a system considered critical or essential to the development of an effective military capability" (DAU 2015). COI 4 is a question about both operational suitability and

effectiveness. A system that will deploy on short notice to an island ahead of detected adversary movement to that same island is essential to accomplishing a deterrence mission over island land grabs. A primary measure of a highly deployable system is the reliability of that system. Is the system ready to deploy at a moment's notice?

5. COI 5: Is This System Affordable?

COI 5 is a question of operational suitability within the confines of the DOD's current budget constraints. Our group made two general assumptions going forward into the system design phase on the issue of affordability. The first assumption was that within the time frame of 2025–2030 there will be no major technological breakthroughs beyond one generation of improvements on current legacy systems. The second assumption we made as a group regarding affordability was to say that all introduced technology had to maintain at least a technology readiness level (TRL) of "8" or higher in order for it to be considered ready for system implementation. According to DOD Desk book 5000.2-R Appendix 6, TRL 8 is defined as, "Actual system completed and qualified through test and demonstration."

C. DESIRED SYSTEM OPERATIONAL REQUIREMENTS

Each COI previously listed must be answered positively by the system design outcome for the system to be considered a success. Inherent in each COI are System Operational Requirements (SOR) that the system must perform in terms of, "system deployment, utilization, effectiveness, and accomplish of its intended mission" in order to achieve a particular COI (Blanchard 2008). SORs are requirements that the stakeholders and system developers formulate based upon stakeholder COIs and the agreed upon operational scenario. For example, COI 1 calls for the system to be deployable. Where and when a system is deployable largely depends upon the context of an operational scenario. The scenario in this case is to deploy the system to an A2AD threat environment. The scenario along with the COIs help assist system designers in formulating the "who, what, where, when, and for how long?" types of questions concerning how a system will operate (Blanchard 2011). Therefore, the SORs that answer

the COIs in terms of an appropriate scenario are SORs that addresses system operation in an A2AD environment.

1. Stakeholder COIs to SORs to STR Traceability

The formulation of Stakeholder COIs and the problem scenario drove the analysis behind discovering SORs. Each group developed specific SORs that supported COI accomplishment. Table 4 represents the Marine group's example of tracing SORs to COIs within the context of the scenario.

As each of the groups worked through the SOR-to-COI traceability in requirements a natural outgrowth of the process was the continued refinement of system requirements at a level below the SORs. System Technical Requirements (STRs) are system specifications for system attributes such as how fast, how big, at what frequencies, and for how long a system will operate (Blanchard 2011). STRs are closely aligned with the Technical Performance Measures (TPMs) that serve as bench marks for evaluating if a system is achieving a certain STR. By definition, TPMs are "measures for characteristics that are, or derive from, attributes inherent in the design itself" (Blanchard 2011). TPMs for our project are covered in greater detail in Chapter VII.

The recursive loop included in the SE process is required throughout the design process due to its integrative nature and is especially important in refining the STRs. The initial STRs are first developed with a vague understanding of their parameters. For COI 1 the system must deploy. And in order to deploy the system has the SOR 1 of deploying to an A2AD environment. And in order for the system to perform SOR 1 to answer COI 1 the system must process certain set of yet unknown physical characteristics. The system must deploy within X hours with a minimum speed of Y knots, and shall be detected no early than Z kilometers from the landing site. The aforementioned STRs are unknown and are not assigned a specific value at first because in later stages of the SE process the groups built models to attempt to define what is feasible and what is not, within the team's scope. How fast can a system we create actually arrive at an island? At this point any threshold values would be either artificially imposed, hindering thought, or both. Establishing solid STRs based upon rigorous analysis is a fundamental part of ensuring a

system is developed that can achieve the higher levels of the requirements hierarchy previously discussed and shown in Table 4.

Table 4. Example Marine Group System Operational Requirements

COIs →	SOR	Marine Group System Operational Requirements
COI 3	M-SOR 1	The system shall deter adversary from occupying an island– COI 3
COI 3	M-SOR 2	The system shall defend against credible threats (DF-21, Cruise missile, Land mines, aircrafts, ships, EW & GPS, SWARM, UAV) – COI 3
COI 3	M-SOR 3	The system shall be able to effectively defend against 1x company of enemy marines – COI 3
COI 2	M-SOR 4	The system shall maintain communication links with USMC and USN high HQ – COI 2
COI 2	M-SOR 5	The system shall communicate with coalition forces – COI 2
COI 3	M-SOR 6	The system shall have the capability to detect and identify friend or foe (surface and air) up to a range of 120 NM – COI 3
COI 1	M-SOR 7	The system shall be deployable to the targeted location in less than <72 hours from Warning Order – COI 1
COI 2 **COI 4**	M-SOR 8	The system shall support indefinitely the logistics requirements for men and equipment operating within the system in an A2AD environment – COI 2 and 4

2. Requirements Analysis Hierarchy

Figure 9 is a system requirements hierarchy showing traceability from the stakeholders traced down thru to individual STRs. The format for the functional decomposition is borrowed from Blanchard and Fabrycky's format of functional decomposition to support requirements traceability (Blanchard 2011).

As previously described, stakeholder needs begin with an analysis of the enemy's current posture and probable future plans. From this analysis of the enemy are born the stakeholder needs that are voiced through COIs. The COIs in conjunction with an operational scenario lead to the development of SORs. And in order to perform the SORs a certain set of STRs must be established by the system design group through modeling and analysis.

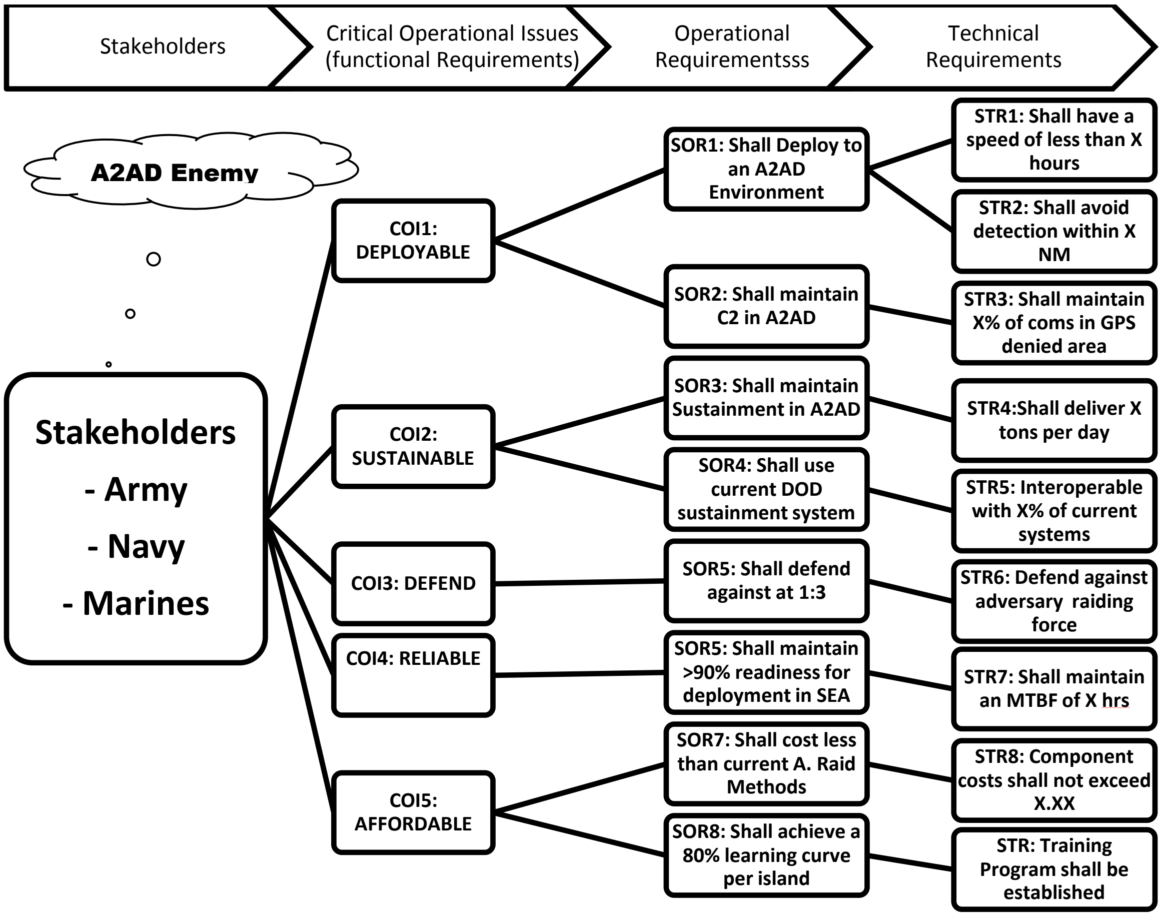

Figure 9. Requirements Analysis Hierarchy

The system requirements were continually developed and updated by the design group throughout the SE process. The sum total of system requirements are what then drives the functional analysis process described in Chapter VI.

VI. FUNCTIONAL ANALYSIS

A. FUNCTIONAL DECOMPOSITION

Functional analysis (including decomposition, analysis, and synthesis) is a fundamental step within the SE process where the complexity of a system or a system concept is divided into functional and sub-functional areas. Decomposing a complex system into smaller subset functional areas assists system designers in visualizing and designing smaller and more manageable parts of a larger system. Designers can take a system such as a vehicle and decompose it down to functional areas such as the drive system, communications system, fuel system, chassis and others. The result of functional decomposition is a more granular understanding of a system design at a functional level, from which functional requirements are determined.

The functional decomposition process begins with analyzing who the stakeholders are and analyzing what stakeholders individually and collectively view as important. In the case of DOD stakeholders the relevance of a system is based upon how well that system serves its purpose in supporting mission accomplishment.

B. TACTICAL AND OPERATIONAL ACTIVITIES

The concept of a military mission and the systems that support mission accomplishment are two different concepts and is a unique point of consideration when designing DOD specific systems. A mission is a defined tactical task that contains agreed upon supporting tasks that define mission accomplishment and the conditions under which those tasks must be carried out along with the standards that measure how well the performer achieved those tasks in support of accomplishing a mission.

Our team began the functional decomposition process with an in depth analysis of the doctrine supporting our DOD stakeholders mission accomplishment needs. Military doctrinal tasks exist separately from any one type of system because they represent an enduring set of needs. To attack, to defend, and to seize are all examples of doctrinal tasks that have endured as military commander’s needs since ancient warfare and these tasks along with others will exist well into the foreseeable future. How those tasks are

accomplished does change with various systems (e.g., sword, horse, armor, tank, airplane), and it is from the system's framework that our team began the process of designing our specific system.

1. Doctrinal Mission Tasks for Amphibious Raid

Our team focused in on the specific wording of our tasking statement where the need for an amphibious raid capability was addressed by the stakeholders. Amphibious Raids are a mission area for the U.S. Marine Corps (USMC) and U.S. Navy as described in the Universal Naval Task List (UNTL) (OPNAVINST 3500.38 2007). However, when appropriate, the U.S. Army is also capable of conducting Amphibious Raids as per the Army Universal Task List (AUTL) (Army FM 7 15 2003). Raid missions generally include small units exercising offensive operations to seize an area quickly in order to gain information, capture personnel or equipment, confuse an enemy, or destroy an enemy plan or capability followed by a planned withdrawal from the area ("Joint Task" 2015).

In order to narrow the scope of the problem and tailor system development to a specific force package our team made the decision to focus on the Marine Corps version of Amphibious Raids as a tactical task. The reasoning behind this decision follows that the Navy plays a supporting role in the delivery and support of amphibious raid forces and the Army defers to Marine Corps doctrine in amphibious operations. Therefore, any solution requiring Marine personnel would also be applicable to Army forces. Our team moved forward using amphibious raid doctrine as a conceptual framework following Navy Tactical Task 1.5.2.4 and Marine Corps Tactical Task 1.12.1.2 from the UNTL. The UNTL defines an Amphibious Raid as:

> To conduct short-duration, small-scale deliberate attacks, from the sea, involving a swift penetration of hostile or denied battlespace. Amphibious raids are conducted in order to secure information, to confuse the enemy, or to seize, destroy, neutralize, capture, exploit, recover, or damage designated sea-based or shore-based targets. Amphibious raids end with a planned withdrawal upon completion of the assigned mission.

Marine Corps doctrine further defines the conduct of Amphibious Raids with Marine Corps War Publication (MCWP) 3–43.1; Raid Operations. The center piece of the

Marine Corps raiding force is the ground combat element (GCE). The organization of the raiding force depends on the mission, enemy, terrain and weather, troops and support available and time available ("Raid Operations" 1993).

Augmenting the Marine Corps component of the raiding force are the naval tasks in support of amphibious raids. Conducting an amphibious raid is no small undertaking, as represented by the sheer number of blocked tasks shown in Figure 10. Our team began the functional decomposition process with a breakdown of all the tactical tasks associated with conducting an amphibious raid. Our premise was that if we knew what must be accomplished we could then better understand how we might tailor a system capable of accomplishing established doctrinal mission tasks. A functional decomposition of Navy and Marine Corps tasks to support a small Marine raiding force yielded a staggering 179 high-level tactical tasks (see Appendix A). The majority of this task burden falls on the Navy in the form of overall support to the raiding force.

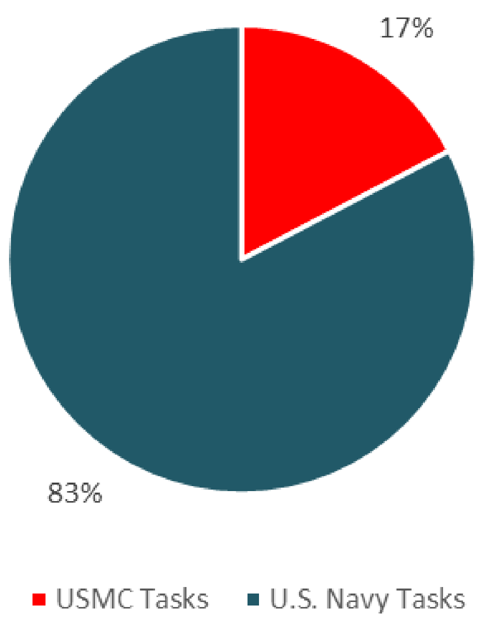

Figure 10. Amphibious Raid Tasks Load

Figure 10 illustrates the information contained in Appendix A. Only a fraction of the 179 tasks involved in conducting and Amphibious Raid are conducted by the Marine

GCE. On this point our team made the decision to scope our problem down to developing only the raiding force system elements required to penetrate an A2AD bubble and support accomplishing our stakeholder's needs.

2. System Boundaries

Our team bounded the system by focusing on the assaulting force and the supporting mechanisms of the system by which a raid is conducted. Our team consensus on bounding the problem is shown in Figure 11. In order to conduct an amphibious raid within the parameters of our problems statement a system must deliver an assaulting force, sustain that force, and defend that force as primary system functions.

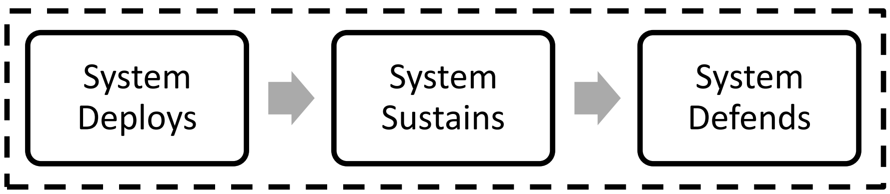

Figure 11. System Functional Boundaries

3. Chosen Doctrinal Tasks

MCWP 3–43.1 describes the essential raiding force organization as having the elements shown in Figure 12. Paring our analysis of the bounded system functions with Marine Corps Doctrine we were able to scope some of the organizational requirements away to exist outside of our system.

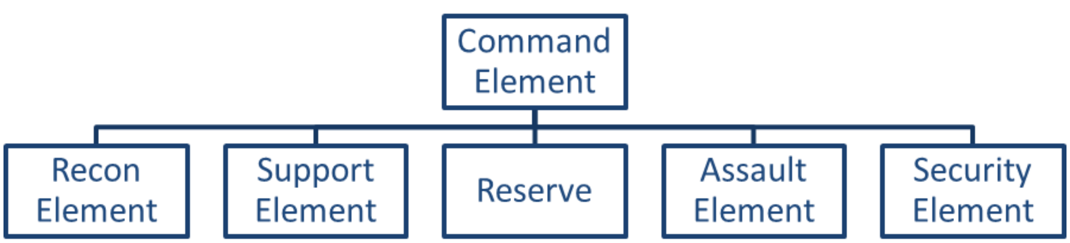

Figure 12. Organization of the Raiding Force (from Raid Operations 1993)

Elements such as the Recon Element and Reserve element were considered out of bounds from the core raid system our team focused on designing. Our team determined that we could exclude the Recon element on the grounds that a reconnaissance mission is an entirely other task set that requires specialized systems dedicated to intelligence gathering. The black arrow in Figure 13 represents moving the reconnaissance element outside the boundaries of our system. We also determined that a reserve element was not required based upon our problem scenario and as a result we eliminated the reserve element entirely from our system as depicted in Figure 13. Our scenario calls for the rest of the fleet to anchor outside of the A2AD bubble and if needed, can assist in a reserve capacity.

Figure 13 shows the genesis of doctrinal scoping that our team conducted in order to establish a doctrinal framework from which to base our system design upon.

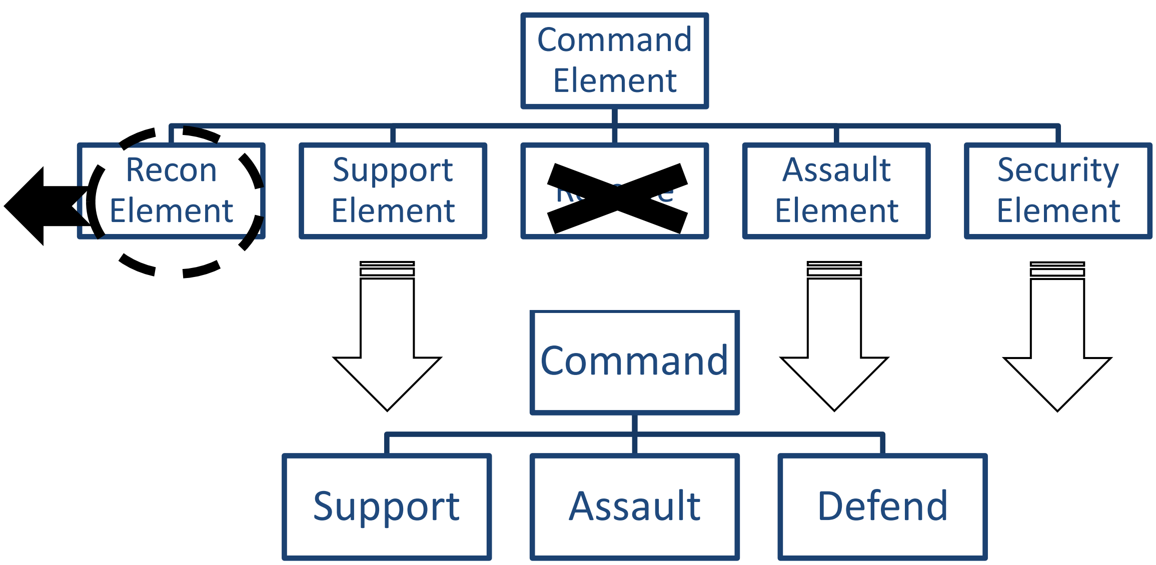

Figure 13. Scoped Organization of the Raid Force

The resulting configuration of a raid force supports our team's assessment of the problem boundary defined in Figure 11, where our system development focuses on assaulting the objective (deploying to a location) supporting the raiding force (sustainment) and defending the raiding force.

4. Operational Activities

In order to make the transition from doctrinal decomposition to system functional decomposition it is necessary to define Operational Activities (OAs). OAs are defined as activities analogous to supporting tasks within military doctrine ("DAU" 2015). They are the activities associated with mission accomplishment and in the case of system design OAs help describe different modes of system operation (Blanchard 2011). The decomposition of OAs is done through assigning functions to accomplish each OA. It is through this subtle connection that the transition from doctrinal decomposition to functional decomposition transpires.

The OAs that best describe the mission accomplishment of conducting a raid are; Assault, Sustain, and Defend which are the same items listed as elements in our doctrinal description. We focused our design efforts in systems design on these three main OAs.

5. Functional Hierarchy

Figure 14 shows the functional decomposition of our system where all of the system requirements listed in Chapter V are collected as one centralized set of requirements describing what the system must do (SORs) and how the system must accomplish its mission (STRs). Below the system requirements in the hierarchy are the system OAs showing the three primary modes of system operation followed by high level system functions. System functions describe in functional action verb terms what the system is physically performing in order to accomplish a particular OA. Functions are best used in the design process by designers describing *what* a system must do before the *how* is defined (Blanchard 2011).

At the very end lies the system component level. The component level is the actual piece of equipment, network, or otherwise physical thing that is brought into existence for the purpose of accomplishing some assigned function. The collection of components ultimately should meet the stakeholder's COIs along with every system requirement generated during the requirements analysis phase (Blanchard 2008)

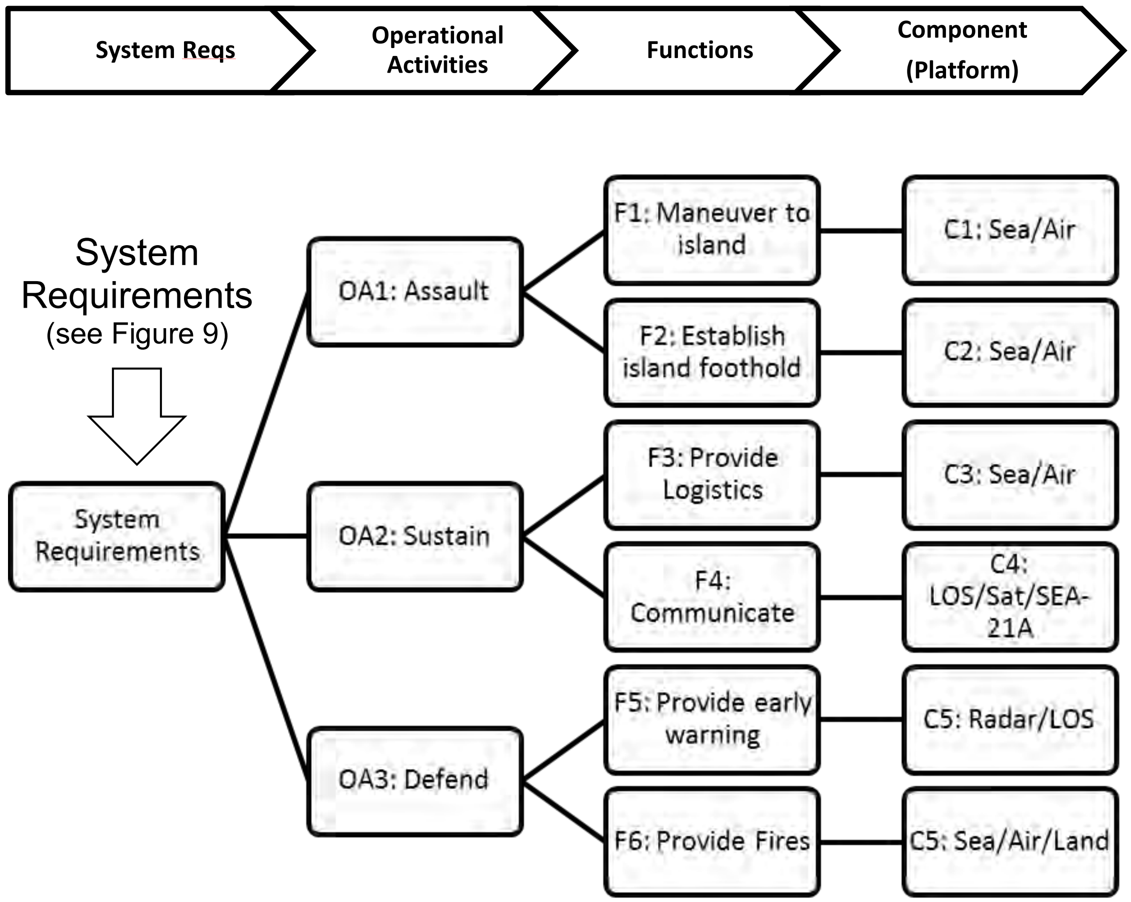

Figure 14. Functional Decomposition Mapped to Platforms

a. General System Functional Decomposition

Listed after the OAs are the primary system functions our team used as a primary case towards achieving our system design. Broadly stated, our system needs to maneuver an amphibious force to an island in a contested littoral area. And after establishing a foothold on a contested island, the system must then support the assaulting force and any follow on force reinforcements that arrive to the island. In order to support the force the system must then provide logistical support to the force and enable the force to communicate with assets outside of the A2AD bubble. Lastly, defending the force is a critical function that our system must perform through early warning capability and defensive fires.

Figure 14 represents general items that could guide our team's search for feasible components capable of fulfilling our system's functional requirements. As stated previously the expectation is that the systems currently in existence in today's fleet will continue to be operationally relevant in the 2025–2030 timeframe.

6. Functional Flow Bock Diagram

Functional flow block diagrams (FFBDs) are an additional method designers employ to accomplish functional decomposition of a system (Blanchard 2011). The FFBDs are useful in depicting a sequence of functional events that can have either linear or parallel relationships. The FFBD shows system flows along a timeline of a system in operation. Normally the FFBD begins with the initial function required for system operation and then closes with the final system function required for system accomplishment. FFBDs at lower levels of system functions may be embedded to show internal functional flows within higher level system functions. Figure 15 is a depiction of our team's FFBD showing the highest level of functional flow.

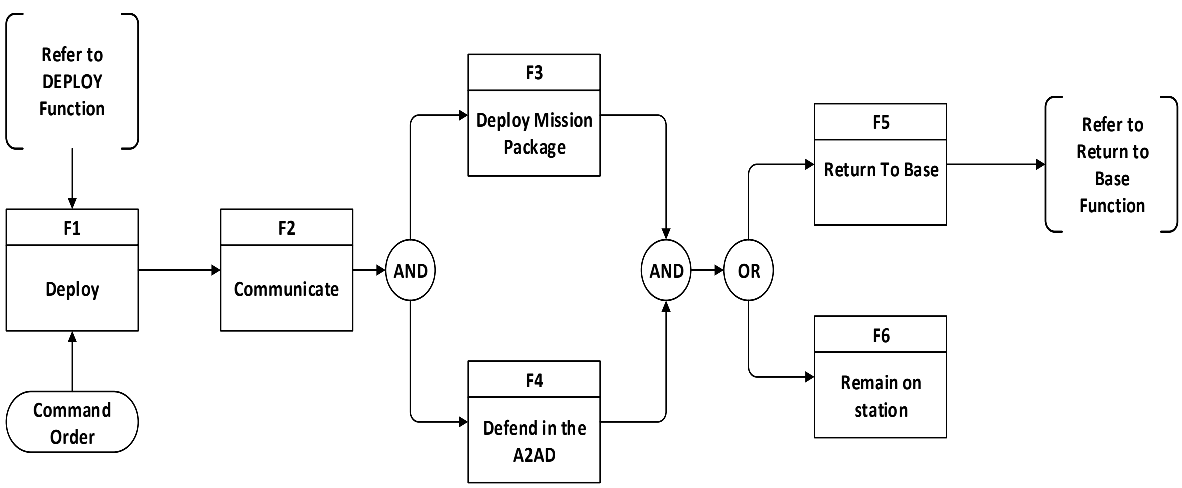

Figure 15. System Top-Level FFBD

The open parenthesis box in Figure 15 refer (REF) to a function that may be decomposed further than what is depicted. In Figure 15, the function "F1: Deploy" is a major function with multiple sub-functions and sub-functional flows contained within the function itself. The reference function for Function "F5: Return to Base (RTB)" is similar

in that the parentheses inform the reader that there are sub-functions and sub-functional flows contained within the RTB function.

The bubble depicting a command order is used to show outside information either from another separate system or a performer, such as a military commander, is initiating a system functional flow. A command order to deploy an amphibious assault force and to initiate penetration of the A2AD bubble would be the prerogative of the local military commander. Our system then would react to this outside input and perform the functions in sequence as one continuous functional flow.

a. System Requirements Traceability

System functional traceability is ensured via strict adherence to placing functions within the system that directly support OA accomplishment. Accomplishing OAs with functions supports the fulfillment of system requirements and ultimately stakeholder COIs. Figure 16 shows an example of system traceability where a stakeholder sets a COI that initiates a process using SE techniques to positively answer the stakeholder's COI. In the example shown in Figure 16 the component selected to fulfill the COI is an MV-22 Osprey tilt rotor aircraft. In later section we will examine the component level of design through a series of COAs using various modeling techniques. Modeling the performance of the MV-22 in fulfilling a function to maneuver and an OA to assault will then inform our designers of the STR possible. Can the MV-22 deliver a force within X hours? If the answer is negative then the process begins again to search out an alternative component. If on the other hand the answer is positive, then the question becomes one of fulfilling the SOR and COI set forth by the stakeholder.

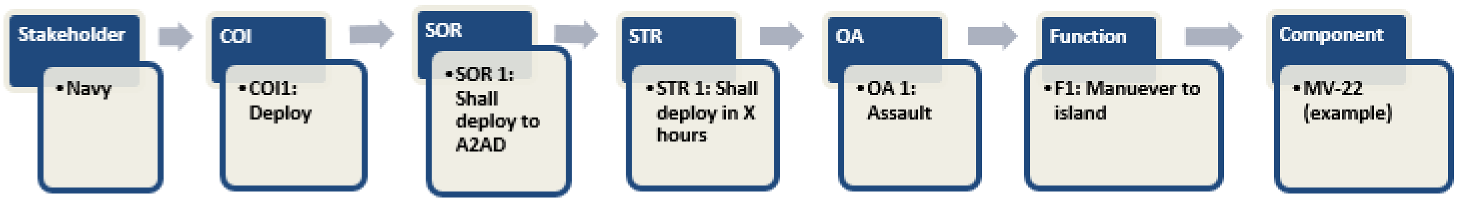

Figure 16. Stakeholder to Component Traceability for COI1: Deploy

VII. REQUIREMENTS ALLOCATION

A. FUNCTIONAL PACKAGING AND PARTITIONING

After functional analysis is completed, the design group begins to form an operational picture of a high level system design. The next step in the SE process is to then begin the functional packaging and partitioning of the system design. Functional packaging is the process of grouping system functions together into groups of functions where similarities between multiple functions and multiple sub-functions exist. The goal is to ultimately partition the system into like functions where a set of components can accomplish multiple functions within a system. The end state is to have as few system components and system processes as possible to accomplish as many functions as possible within a system design. This methodology reduces system complexity and increases system efficiency by driving down the number of components and possible interactions between components while at the same time increasing the utility of each component within a system (Blanchard 2008)

If the goal of the project was to build a completely new system our team would then have to develop "*design to*" requirements for various items of system equipment (Blanchard 2008). We would have to design our systems and sub-systems to meet stakeholder needs and build a custom system. This process is a detailed engineering endeavor in which every component, assembly, and sub-assembly within a system is designed and packaged to meet allocated system requirements.

Ultimately the purpose of the SE process is to meet the expectation of the customer. For each stated requirement that a stakeholders expresses, there should be a component, or mixture of components that work to satisfy those stakeholder requirement. The existence of a component within a system such as a major end item like a chassis, or a small component like a headlamp, must exist within the system for some specific purpose in support of a stakeholder requirement. If a component exists within a system that serves no direct or indirect stakeholder need, then that component is superfluous and should be eliminated by the design group to reduce complexity.

B. ALLOCATION OF SYSTEM LEVEL REQUIREMENTS

Our team framed the project problem scenario in the near term, 2025–2030, where we would look at existing technologies that are currently within the DOD inventory. At the heart of our team project was an emphasis on analyzing existing technologies capable of fulfilling our stakeholder needs. In order to accomplish this task we began by searching the DOD for systems that could potentially fulfill our system requirements.

Within the DOD there exists an incredible variety of capability in terms of land, sea, and air domains. Much of this DOD capability exists in a compartmentalized format belonging to individual units, Combatant Commands, and services throughout the DOD with very little cross utilization. Our team's approach was to take an academic view on creating the system and to ignore current DOD practices where dissimilar capabilities are not mixed and matched quickly in an integrated and responsive format. For instance, within the DOD, the ability to network and pull disparate systems together quickly, in order to seize an island, does not exist. Deploying a C-17 cargo aircraft, with an MV-22 tilt-rotor aircraft, supported via LCS using airborne Soldiers and/or Marines to seize territory, does not exist without substantial planning and joint coordination. Our team's project examines this current gap in capability integration and our project proves that there are a set of existing capabilities within DOD, as a whole, to accomplish the mission of quickly seizing an island.

1. Major Systems

Major systems we considered were the various system platforms that exist within the DOD. For transportation and delivery requirements we examined large cargo transport aircraft such as the C-5 Galaxy and the C-17 Globemaster. We also looked at surface and subsurface naval assets such as surface LCS and SSGN class submarines.

2. Sub Systems

The sub-system portion of our analysis examined various Marine and Soldier Force Packages that would be operationally suitable for deployment to an island for the purposes of quickly occupying territory. Our team designed small, company sized,

Marine and Soldier force packages that were suitable and effective in a low, medium, and high treat mission environment.

C. TRACEABILITY OF REQUIREMENTS

Figure 17 shows the results of a notional SE process where the requirements analysis and functional analysis are complete and the design group experiments with selected components that meet allocated system requirements. In Figure 17 a C-17 is chosen for transportation and maneuvering to an island. The C-17 in this case would fulfill several system requirements such as speed, stealth, maneuverability, timeliness, and so on. Thus, the requirements in a sense were allocated to selected material solutions through the selection and testing of possible platform solutions.

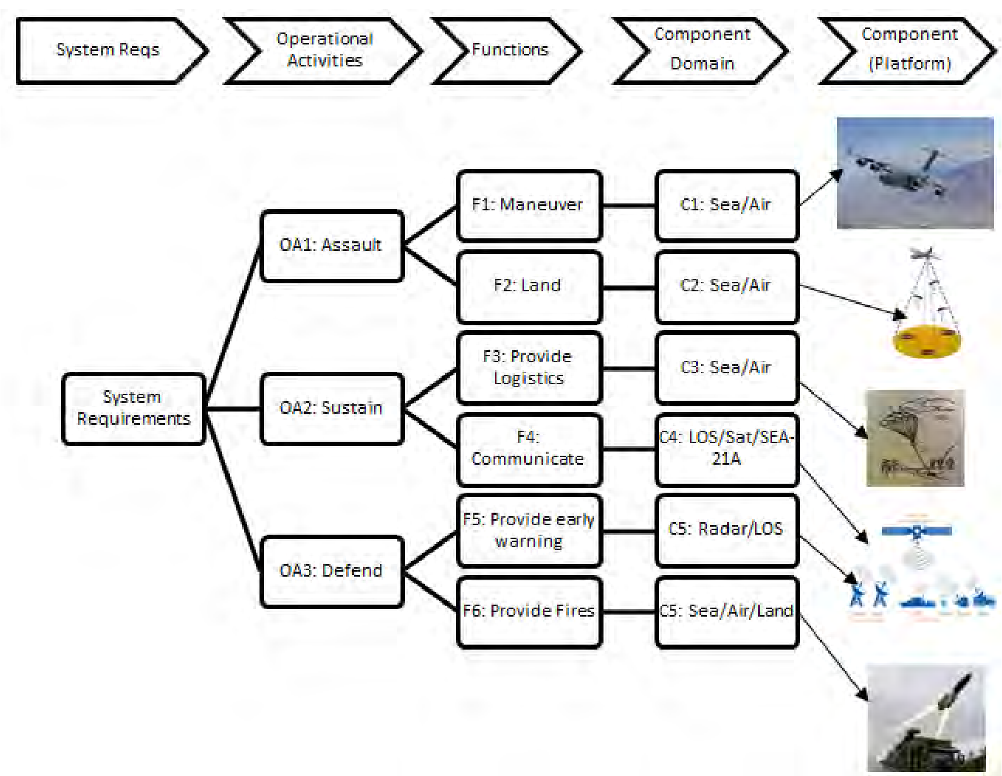

Figure 17. Concept System (images in graphic from Jane's 2015)

The design group selects candidate components to form a system and then begins the process of modeling aggregate system performance against other potential system

configurations. Many of the unanswered "X & Y" Technical Performance Parameters (TPM) shown previously in Figure 9 are then calculated and refined through this process of modeling and exploring of the design space. Hence, the iterative loops within the SE process shown in Chapter I are utilized. As the design group modeled and refined the design, more and more of the previously unknown design parameters are worked out and a system design begins to take shape and emerge and an integrated SOS.

1. System Synthesis

"Synthesis refers to the combining and structuring of components in such a way as to represent a feasible system configuration" (Blanchard 2008). Our design groups began the process by selecting a combination of existing platforms that they believed would support system requirements. After the system was formed the groups then ran each of the COAs through an agreed upon set of evaluation criteria models whereby each COA was fairly evaluated and creating options for our stakeholders to choose from that we believe are both effective and suitable for the mission within the problem statement. Figure 18 shows the processes we used to develop our COAs. The COAs were a combination of different existing platforms, each with defined technical parameters that we resourced from open and unclassified sources. At each modeling iteration's conclusion, our design group refined its COA designs.

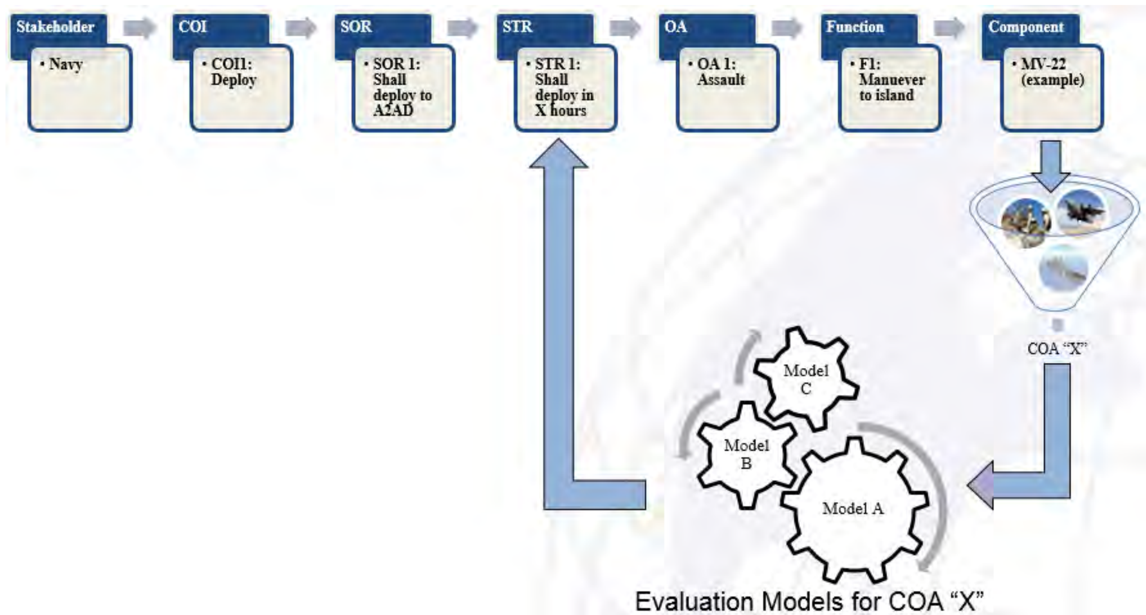

Figure 18. COA Evaluation Process

The process shown in Figure 18 is useful for exploring the design space. Questions during the process of system design often lead to more questions than to answers. In Figure 18 the example shows that the requirement is for the system to deploy to and A2AD environment and that the system must be able to deploy within X amount of hours. At this point in the design process a design group may know what the tactical requirement is, however they cannot know what is technically feasible until they examine the COA solution with some form of modeling analysis. The following chapters explain our process for developing COAs and our evaluation methodology in more detail.

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VIII. U.S. NAVY GROUP SOLUTIONS

A. SCENARIO RESTATED

In approaching our development of potential Navy CONOPS, the Navy group focused on the final South China Sea scenario as both the most likely and most challenging for the fleet to support. This scenario demands the rapid insertion of a company of Marines onto an island in an A2AD environment in order to reopen the area to commercial and military traffic. The anti-ship cruise missile threat is deemed too severe to utilize traditional amphibious vessels and so the Navy must utilize lower-cost platforms to accomplish the same mission. Furthermore, the density of the threat to American naval platforms implies that fleet commanders would be unwilling to leave the ships next to the island in a support capacity once the Marines are ashore, thus leading to a requirement that the ground forces bring enough equipment and armament to defend themselves from a gamut of potential threats. If the ships were able to remain in place to support the ground forces, any capability they bring to bear would be considered an unexpected bonus.

This scenario drove our overarching requirement to move approximately one hundred and fifty ground troops, with their supplies and enough heavy equipment to protect themselves from potential air or surface threats without utilizing our purpose-built amphibious ships or developing an entirely new platform.

B. USN REQUIREMENTS ANALYSIS

1. Critical Operational Issues

The Navy group has five specific COIs which help to define the systems requirements. The five COIs are:

a. COI 1: Deployable

Can the selected Navy force package beat the advisory to an island? The designated location for forward basing will play a significant role in timeliness of reaching the island.

b. COI 2: Sustainable

Can the selected force package deliver the necessary troops and supplies to accomplish the mission?

c. COI 3: Defendable

What defensive capability does the force package provide against air, land and sea threats? This is on the edge of our design space, it is assumed that intelligence and available sensor networks allow us to be informed of adversary's landing force on the island.

d. COI 4: Reliable

Is the force package ready to be deployed on moment's notice? Can this posture be maintained indefinitely or is there a required downtime at a specific frequency?

e. COI 5: Affordable

Can we accomplish the mission without risking the loss of a high value asset? The force package will be comprised of legacy systems and must meet realistic DOD budget constraints.

C. USN REQUIREMENTS

These six system requirements must be met to accomplish corresponding COIs:

1. The system shall be deployable to the targeted location in a time limit (such as less than <72 hours) from Warning order. – COI 1,4
2. The system shall support indefinitely the logistics requirements for men and equipment operating within the system in an A2AD environment. – COI 2
3. The system shall be capable of delivering troops and supplies that will deter an adversary from occupying an island. – COI 1
4. The system shall provide fire support as necessary for forces occupying the island. – COI 3
5. The system shall not require high value assets to enter the A2AD environment. – COI 5
6. The system shall operate in an A2AD environment - COI 4

D. USN FUNCTIONAL ANALYSIS:

In designing courses of action, these six Navy functions must be considered:

(1) Maneuver – (COI 1, 2, 4)

The system must be able to move and transport personnel and goods within the A2AD environment, to include contested littorals.

(2) Land – (COI 1, 2, 4)

The system must be able to deliver its forces ashore, either via an airlift using organic assets (vertical takeoff and landing aircraft or helos), deployable small boats, or roll on roll off ramp pier side.

(3) Provide Logistics – (COI 2)

In addition to the initial landing of troops, hardware, and supplies, the system must be capable of follow on delivery of replenishment.

(4) Communicate – (COI 3, 4)

In order to facilitate operations ashore, the system must be able to communicate with the shore forces utilizing line of sight or other non-satellite based communications networks.

(5) Provide Early Warning – (COI 3, 4, 5)

In the vulnerable landing phase, and while troops are ashore, the system must be able to provide air, sea, and undersea detection coverage until such capabilities are replaced by the forces ashore.

(6) Provide Fire Support – (COI 2, 3, 4, 5)

The system should be able to provide close in fire support and answer calls for fire until the forces are established ashore.

E. USN DESIGN SYNTHESIS: COAS

The expected operating environments are high risk in nature. Due to this fact, the Navy desires to maintain all high value assets outside of the respective A2AD environment. The following COAs have been designed to meet the developed system requirements.

1. COA A: Littoral Combat Ship (LCS) Ferry

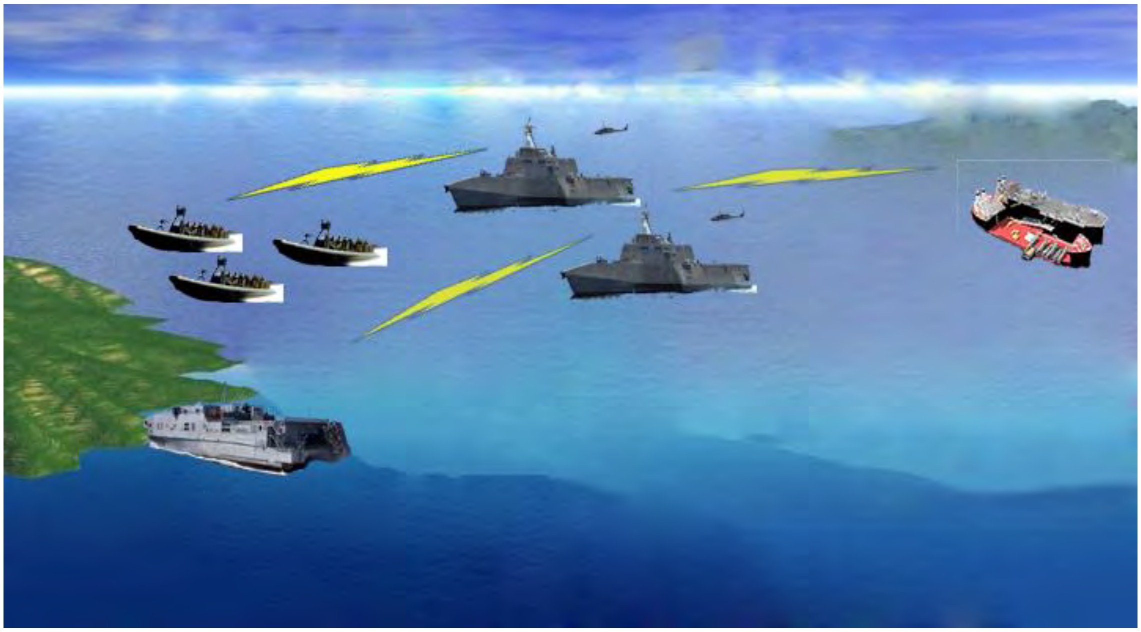


Figure 19. OV-1: LCS Ferry

As discussed in our chosen scenario, the goal of our operation was to penetrate an A2AD environment in the South China Sea without risking major assets. A natural response to this caveat would be to explore what forward-deployed assets would be available within the next ten to fifteen years. With the current plan to base them out of Singapore, the LCS was a suitable fit for our first CONOPS. Its fast speed and large cargo capacity meant it would take relatively few platforms to move the required number of marines and, coupling it with a joint high-speed vessel's (JHSV) ability to transport heavy equipment, no asset costing more than $600 million would be needed to enter the high threat area. This meets COIs 1 and 3.

Under this concept, the Marines and their equipment would be flown to Singapore where the equipment would be loaded on a JHSV and the troops would be divided between up to four LCS, depending on the number of troops required. Due to berthing and messing restrictions, an LCS would likely only be able to carry 75 Marines for any length of time, assuming containerized living units were available for installation. However, if the destination lay within a day's steaming and overnight accommodations

were not required, that number could likely be doubled. A single JHSV, with its 600-ton capacity, is capable of transporting all of the equipment needed to support the Marines, regardless of which force package they deploy.

Once the ships are loaded, they would sprint toward the target island at maximum speed. Once off the coast, the Marines would be delivered (COI 2) to the shore via the LCS' three 11-meter rigid-hull inflatable boats (RHIB) while its embarked helicopters assisted in offloading cargo from the JHSV, assuming no shoreline was suitable for the vessel's roll-on/roll-off ramp. The force packages are designed to be relatively self-sufficient, however if the LCS are able to remain on-station, they could potentially provide support in the form of mine clearance, communications and networking (COI 5), anti-submarine warfare, anti-air warfare, and anti-surface warfare (COI 4). Most importantly however, would be the ability of the ships to receive and refuel helicopters, enabling them to act as mobile resupply stations for the Marines.

A slight adaptation of this concept would be the employment of an afloat forward staging base (AFSB) or amphibious readiness group (ARG) just outside the A2AD threat area. Rather than flying the troops and equipment to Singapore, the ships could sprint to these larger vessels, receive their cargo, and then ferry it to the target island. The ARG or AFSB would then be kept outside of the most severe threat area and could also serve as logistics or command and control hubs. This potentiality, however, is dependent on the availability of sufficient forces and equipment near the target OA. Further information and specifications for the LCS and JHSV are referenced in Appendix B.

2. COA B: Over the Horizon Landing Craft Utility (OTH LCU)

The OTH LCU concept provides solutions to many of A2AD problems. Given a scenario where one or more landing platform docks (LPD) or landing helicopter docks (LHD) operate within the vicinity of the islands, there is definite potential to provide a rapid response to an island-grab threat.

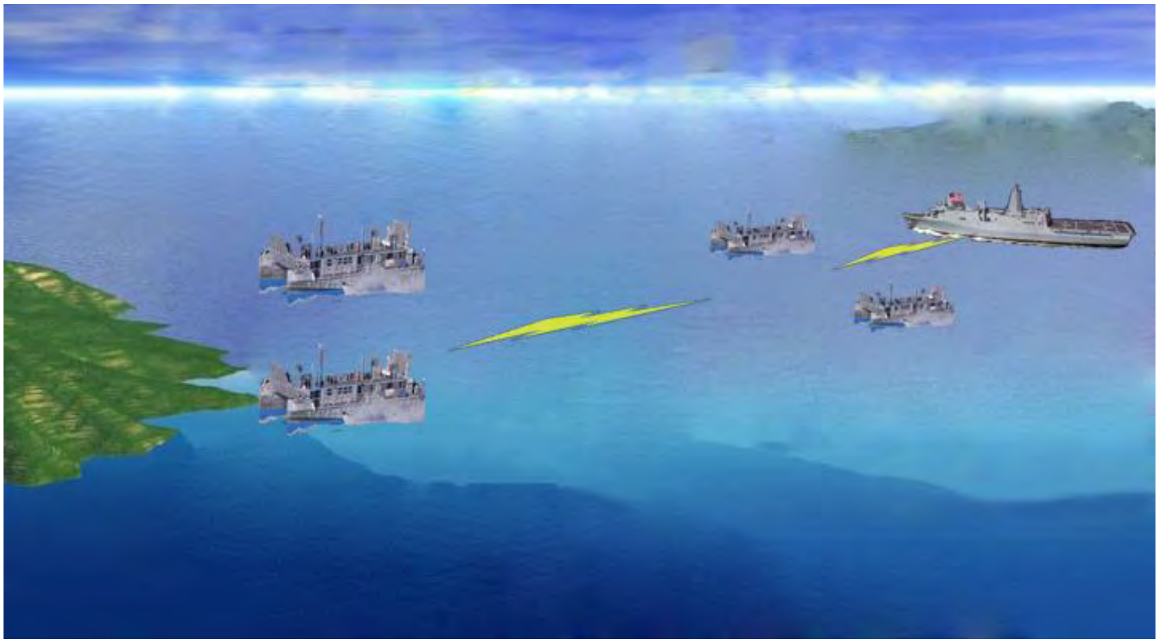


Figure 20. OV-1 Landing Craft Utility

The OTH LCU concept provides solutions to many of A2AD problems. Given a scenario where one or more landing platform docks (LPD) or landing helicopter docks (LHD) operate within the vicinity of the islands, there is definite potential to provide a rapid response to an island-grab threat.

The OTH LCU concept allows for the mobile positioning of assets offering a level of flexibility with regards to changing threat locations. Typical to the existing amphibious assault style, the LPD would have the capability of launching a single LCU at a distance beyond the A2AD environment. The LHD class of ship, however, is capable of supporting a capacity load of three LCUs. The LCU's would then be able to infiltrate the threat area and approach the island as both a smaller target than the amphibious ship, and as a distributed force (COI 1). Additionally, the LCUs are capable of multiple round trips, providing the potential to deliver not only troops, but cargo and supplies as well (COI 2). The limiting factor in the number of LCUs involved is directly impacted by the number and class of amphibious ships operating within the vicinity of the A2AD environment.

When acting independently, a LCU possesses no significant offensive or defensive capability. Its only objective is to transit from ship to shore as expeditiously as possible. However, there are numerous tactical aircraft and support elements organic to the larger ARG on which the LCU is operationally dependent. The LPD platform (San Antonio Class) is capable of carrying up to four CH-46 Sea Knights, or five MV-22 Ospreys. The LHD (Wasp Class) carries a standard compliment of six AV-8B Harriers, four AH-1W Super Cobra attack helicopters, four MV-22 Ospreys, four CH-53 Sea Stallions, and three UH-1N Iroquois, and is capable of handling several other helicopter variants. Between the two classes of amphibious ships, it is possible to provide air and surface support for inbound LCUs (COI 3 and 4).

The drawback to operating amphibious vessels so close to an A2AD environment is the obvious cost associated with it. While able to bring many guns to the fight, the idea of introducing a large, high-value unit to the environment defeats the purpose behind using less expensive assets. The risks and rewards of such actions must be carefully weighed. Further information and specifications for the LCU are referenced in Appendix B.

3. COA C: MV-22 with Amphibious Ship or Mobile Landing Platform Support

COA C provides a combination of high speed and long distance, and may be a better consideration if the A2AD threat sphere is large in reference to the intended target island. The flexibility of the MV-22 allows it to either originate from shore, or as an embarked squadron aboard an L-Class ship (LHA/LHD/LPD). The result is all high value assets are maintained outside of the A2AD bubble (COI 5).

While not a unique ability on its own, in that there are other aircraft such as the CH-46 and CH-53 that can perform similar operations, neither craft have the range and speed of the MV-22. Additionally, instead of an L-Class ship, if a Mobile Landing Platform (MLP) is in the area of responsibility (AOR), the MLP can serve as the host platform and prepositioning station for the materials needed (COI 1, 2).

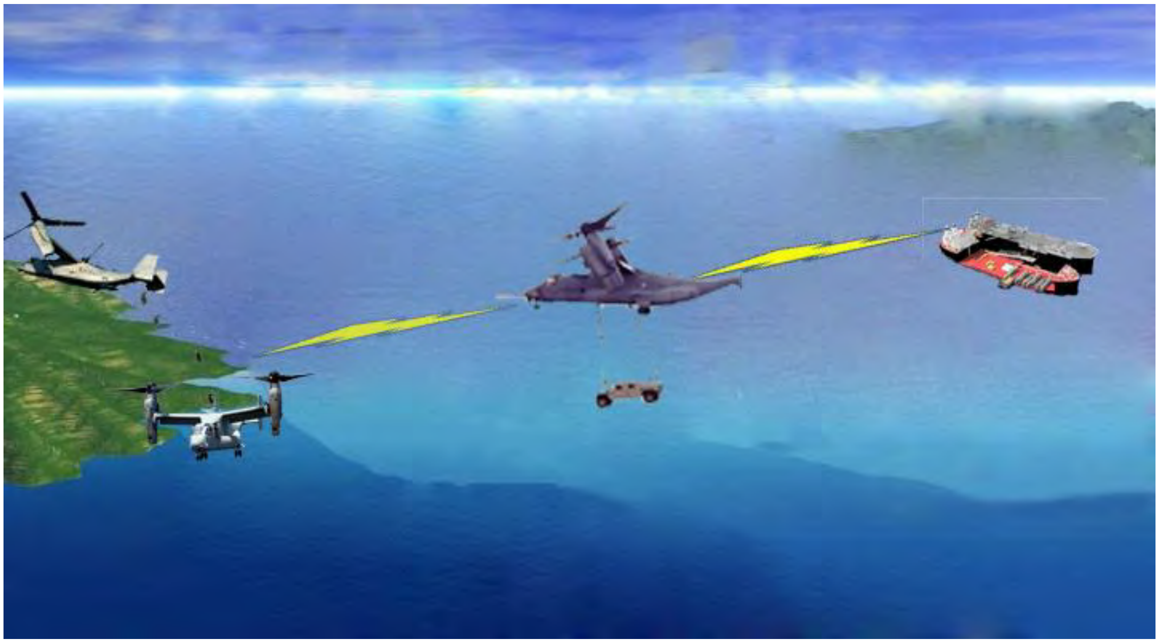


Figure 21. OV-1 Delivery via "Organic" Air Assets

Upon selection of that COA, the Marines and associated equipment would be flown to the nearest forward base of operations (e.g. Singapore or Manila, in reference to a South China Sea scenario). Simultaneously, the MV-22s would fly to the same location and be prepared for transport. If an amphibious landing ship is in the vicinity with an embarked MV-22 squadron, this asset could be maneuvered to respond directly to the situation, and act as the on-scene commander (COI 4). Once the troops, supplies, and equipment are loaded onto the MV-22s, the squadron would fly to the island, refueling midair or via "lily pad" in the form of a naval asset, and then deliver the ground forces to the island.

Other than the speed and distance advantages, the airborne delivery negates any concern for potential naval mines, and mitigates any possible interception from enemy small boats. Future MV-22 upgrades including the CV-22 variant, may allow the aircraft to provide limited close in air support during the delivery (COI 3). Finally, the flexibility and payload capacity of the MV-22 allow for sling loading, midair refueling, and Para drops, should the mission parameters call for such options. Further information and specifications for the MV-22 are referenced in Appendix B.

4. COA D: SSGN with C-17 Support

The SSGN concept provides a unique covert solution to the problems faced in an A2AD threat environment. The SSGN is a modified ballistic missile nuclear submarine that has the capability of transporting special operation forces (SOF) and some limited supplies. The actual troop capacity for an SSGN varies based on expected duration of the required underway time. Required transit or loiter durations exceeding two weeks reduces the troop capacity of an SSGN based on sustainment requirements. Potentially, in 10–15 years the Virginia class submarine will have a payload module that would closely mirror the current SSGN SOF capability. This payload module would supplement the SSGN capacity increasing reliability and availability (COI 4).

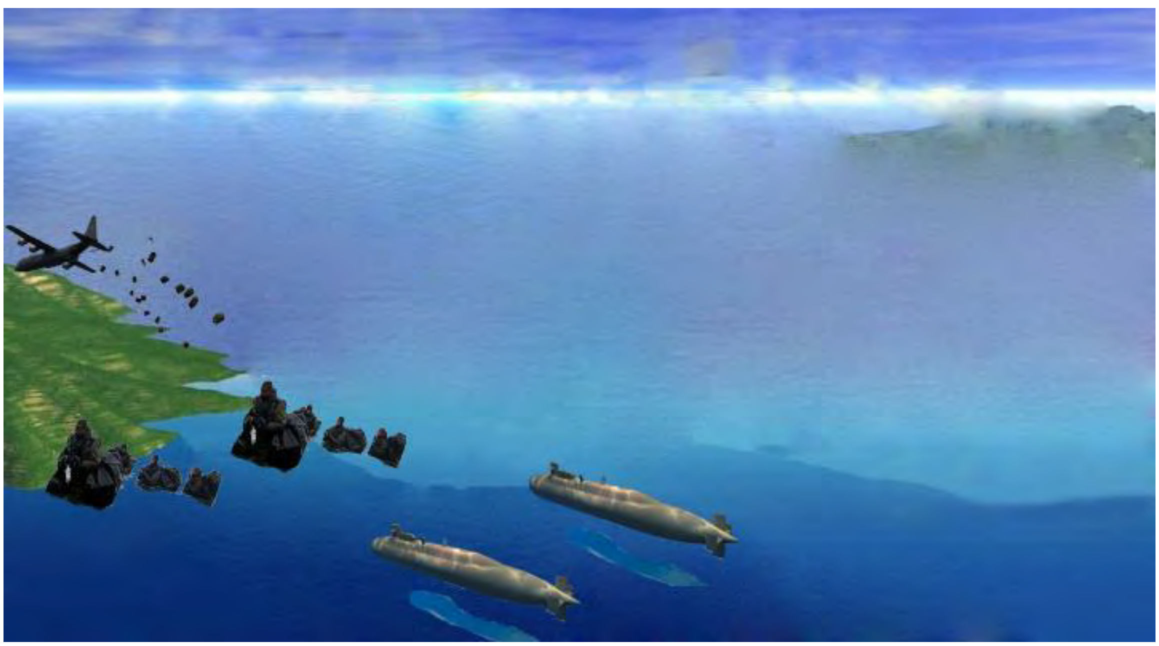


Figure 22. OV-1 SSGN with C-17 Support

The South China Sea scenario would require that all four SSGNs be forward based in either Singapore or Subic Bay to meet reliability and timeliness requirements (COI 4). Troops and supplies would also be forward based or flown in at moment's notice. Once deployed the SSGNs would transit submerged to the selected island while remaining undetected. The SSGN in of itself is a high value asset but its ability to remain

undetected significantly reduces risk of loss during this scenario (COI 5). Once located off the target island, the SSGNs would verify that the environment was safe for surface operations without being detected (COI 3). After surfacing, troops with their supplies would man inflatable zodiac boats topside in preparation for heading ashore. Once troops were in route to the island, the SSGNs would transit to periscope depth were they could remain undetected while maintaining communications with the deployed troops as well as command and control (C2) (COI 1). The backup method of communications for land forces would be via line-of-sight to the offshore SSGN (COI 3). Troops on land or the SSGNs would provide coordinates to C2 for the purpose of supply airdrops via C-17s (COI 2). The C-17s would deliver the necessary material required for defense, support and sustainment (COIs 2 and 3). As necessary, the SSGNs could loiter in the AOR and be ready to provide fire support as necessary via Tomahawk missile strikes (COI 3).

Some potential disadvantages of utilizing SSGNs is that they are limited in the amount and size of supplies they can carry, number of SSGNs required to deliver larger force packages and high value asset cost. The material carrying capacity of SSGNs is negated in this COA with the use of C-17s to deliver required supplies to the island. The risk of exposing a high value asset to the A2AD environment is reduced by the covert nature of the SSGN. The SSGN’s advantages over other similar adversary platforms, particularly in the areas of sensors and detectability (or lack thereof) cannot be overstated. Currently the United States inventory of SSGNs sits at four, which if this COA were utilized would require all four of them to be forward based to achieve the desired reliability and availability. A future Virginia-class submarine with an installed Virginia Payload Module could supplement the SSGN force and would ensure that SSGNs were available for other missions if this COA were put into place. Further information and specifications for the SSGN and C-17 are located in Appendix B.

F. USN COMPONENT/PLATFORM MATCHED TO FUNCTION

After careful analysis, it was determined that there are three major functions that any Navy COA should be able to support when combined with its attached Marine

package. Every system must have the ability to support, assault, and defend the respective territory to which it is deployed.

1. Assault

The ability to "assault" from a naval perspective must be given some flexibility with regards to interpretation. For this circumstance, "assault" is divided into two potential options: having the ability to deliver materials, and having the ability to deliver troops/personnel. In each of these circumstances, there is a limited selection of platforms that are provided to choose from: LCS, SSGN, C-130, LCU, MV-22, and JHSV. While the LCS and the JHSV has the capability of supporting more troops and cargo carrying capacity, the MV-22, and C-130 can provide smaller numbers but more rapidly. The SSGN can infiltrate and deploy assets while maintaining a greater level of stealth and element of surprise; however its payload capability is limited. The OTH LCU, while not an asset currently in our arsenal, is one that can be easily augmented due to its current existence in other nations. While multiple trips with an OTH LCU are required, both cargo and troops can be transported.

2. Sustain

The ability to "support" is also divided into two subcomponents supporting the need to support personnel and sustain material on location. Also viewed as the ability to sustain assets in theater, the continued support of COA options can quickly become one of the most complicated processes. Providing the necessary resources (food, water, and medical supplies) for personnel becomes a requirement in any forward deployed area. Also, maintaining that all equipment continues to operate in theater also ensures that assets can support the third required function, to "defend." The LCS and JHSV can carry more supplies, but requires the use of a dock, small boats, and vertical resupply techniques in the movement of gear and cargo; whereas a C-130 can be used to drop supplies by air (a more visible approach and lower supply volume, yet effective when time is of the essence).

3. Defend

In the defense of self and assets assigned to an island, there are two areas of the "defend" function that must be taken into account: the capability to provide surface fire as well as anti-air coverage. In an ongoing A2AD environment, a Blue force must be able to retain the capability to extend radar/early warning as well as engagement range. The most qualified asset for this exact function is addressed with surface ship platforms. Whether they are the assault asset or the sustain asset, they will all require to be the defending asset when in the OA.

G. USN CONCLUSION

In our development of four potential deployment methods, we did our best to map currently existing (or easily acquired) platforms to the functions demanded by our scenario. The platforms must be relatively cheap, fast, and capable of carrying large numbers of troops and equipment in over the horizon operations. Once the functions were determined, and platforms assigned to each, it became a matter of piecing the puzzle together to create a variety of options that each provided unique advantages and disadvantages. These factors were ultimately assigned numerical values in order to then determine which option is "best," depending on the criteria assigned by stakeholders. Because no analysis can ever predict every possible eventuality, our approach evolved into creating a menu of options for a stakeholder, as opposed to settling on a single, "best all around" COA.

IX. U.S. MARINE CORPS SOLUTIONS

A. USMC ORGANIZATIONAL STRUCTURE

1. Elemental Framework

The USMC is the smallest arm of the United States Armed Forces. Nevertheless, being a combined force arm, it is capable of being deployed to most parts of the world in a short period of time to wage asymmetric and flexible warfare in a myriad of changing battlefield scenarios.

The key organizational structure of the Marine Air-Ground Task Force (MAGTF) is generic across any size of USMC fighting unit for all missions and type of military operations. The four key elements comprising Command, Ground Combat, Aviation Combat and Logistics Combat make up this generic structure of the MAGTF.

The unique framework shown in Figure 23 distinguishes the USMC from the U.S. Army (USA) in the sense that the various elements are combined under a single commander at the lowest level of command, as compared to the USA where a single command for the mentioned elements are combined (joint) only higher up the command chain. By virtue of this generic organizational structure, USMC commanders have better command & control of air and ground elements, which greatly enhances the effectiveness of the USMC's joint-warfare tactics ("USMC" 2009).

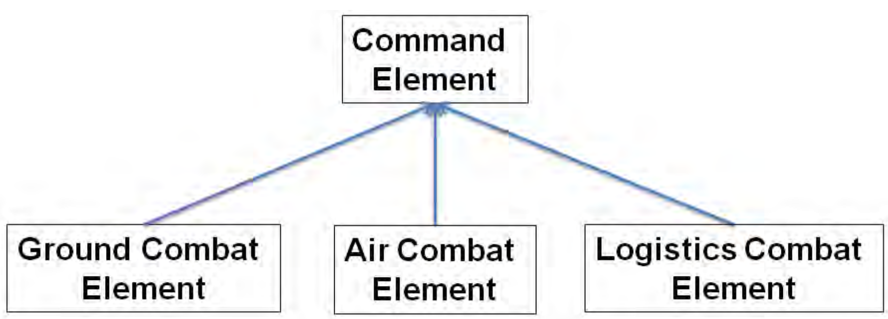


Figure 23. Overview of the generic organizational structure of a USMC unit

a. *Command Element*

The Command Element is made up of ISR and communication units, and is directed by a headquarters unit. This element is the direct higher level authority that coordinates battle efforts amongst the three combat elements ("USMC" 2009).

b. *Ground Combat Element*

In Ground Combat Element, infantry units form the bulk of the force element, with sufficient support from armor, artillery, combat engineer and reconnaissance units. Figure 24 illustrates the standard make-up of the Ground Combat Element.

Figure 24. Overview of a Ground Combat Element (from USMC 2009)

c. *Air Combat Element*

In Air Combat Element, tiltrotor, fixed, and rotary wing aircrafts along with their crew make up the bulk of the force element. Additional units such as control & communications, motor transport, supply and maintenance, and aviation command make

up the rest of the elements ("USMC" 2009). Figure 25 illustrates the standard make-up of the Air Combat Element.

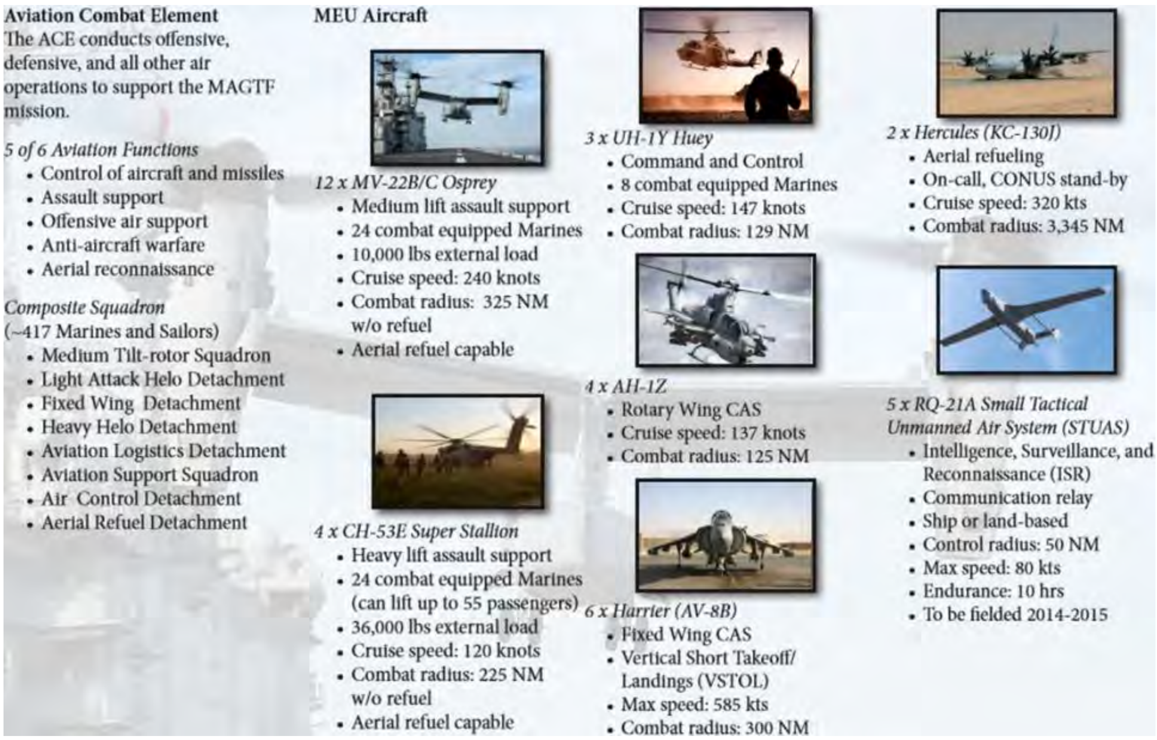


Figure 25. Overview of an Air Combat Element (from USMC 2009)

d. Logistics Combat Element

Combat service support units make up the Logistics Combat Element. These units include motor transport, supply, medical & dental, and maintenance. Figure 26 illustrates the standard make-up of the Logistics Combat Element (USMC 2009).

Figure 26. Overview of a Logistics Combat Element (from USMC 2009).

2. Marine Air-Ground Task Force

Marine Air-Ground Task Forces are units of varying size designed on an ad hoc basis to accomplish a single mission. There are three fundamental echelons of MAGTF force packages that will be described in this section.

a. Marine Expeditionary Unit

The smallest fighting unit within the framework of a MAGTF of the USMC is the Marine Expeditionary Unit (MEU) of approximately 2,200 men. Each MEU is commanded by a Colonel, and is designated to be a quick reaction force that is able to be deployed for any type of operations within the USMC framework. Figure 27 illustrates the standard make-up of a Marine Expeditionary Unit. In addition to the USMC elements, the MEU also includes supporting elements from the U.S. Navy (USN) (USMC 2014).

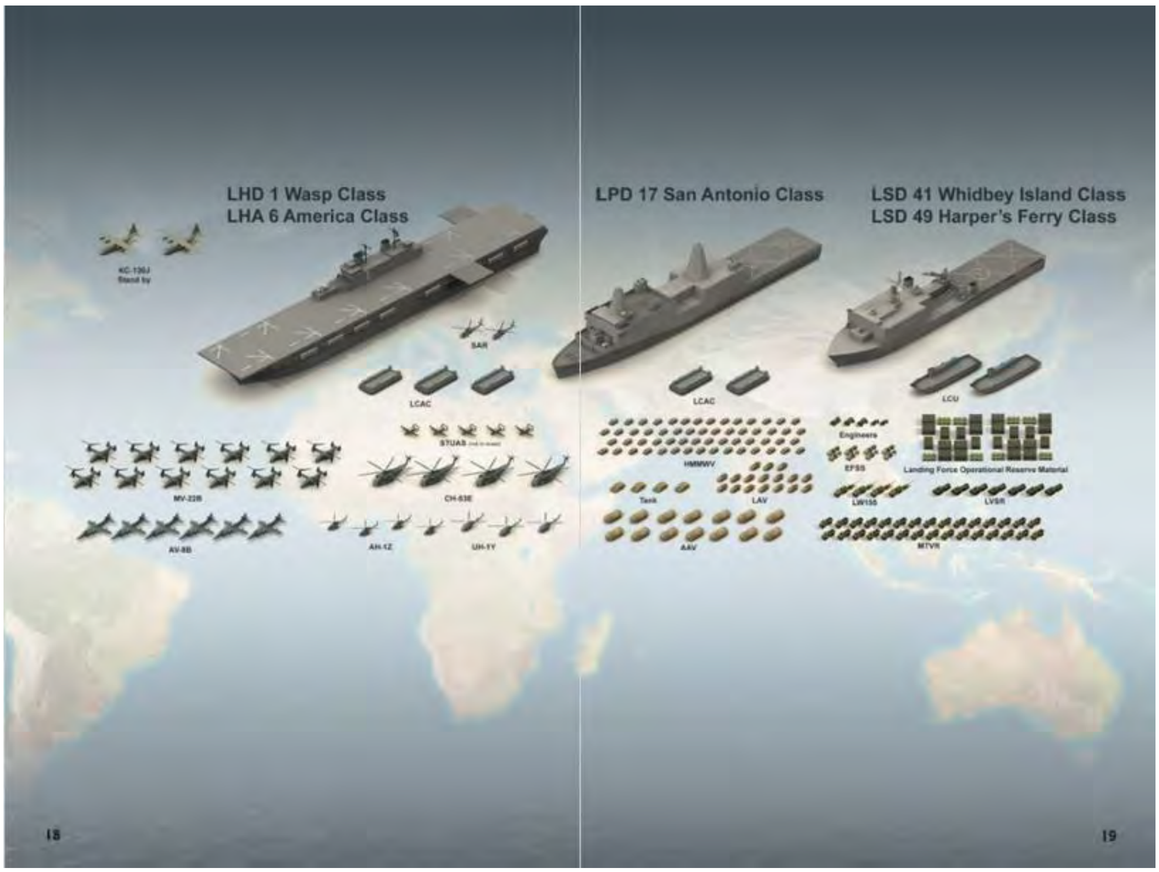


Figure 27. Overview of a Marine Expeditionary Unit with Support Ships (from USMC 2009).

b. Marine Expeditionary Brigade (MEB)

The Marine Expeditionary Brigade (MEB) is the next higher level of fighting unit within the USMC, and each MEB is commanded by a Major General or Brigadier General. Depending on the operational scenario, a MEB is made up of anywhere between

4,000 to 16,000 marines & sailors, made up of several MEUs depending on the mission. The MEB is designed to sustain itself for up to 30 days in an expeditionary environment. Figure 28 illustrates the standard make-up of a typical Marine Expeditionary Brigade (USMC 2014).

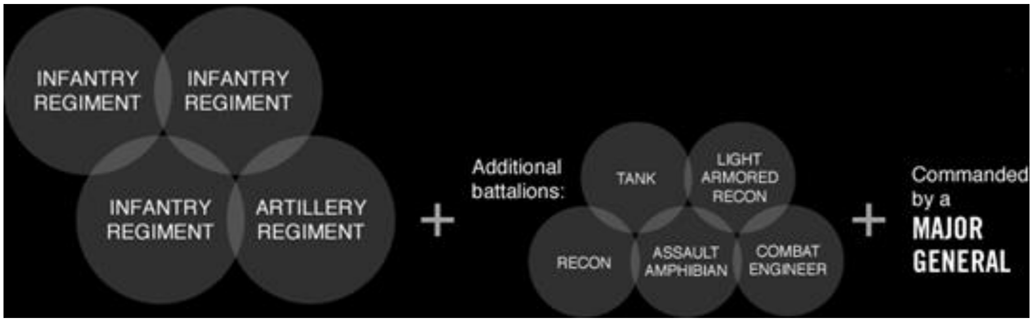


Figure 28. Breakdown of a Marine Expeditionary Brigade (from USMC 2014)

c. *Marine Expeditionary Force*

The Marine Expeditionary Force (MEF) is the highest level of a fighting unit within the USMC. Each MEF is commanded by a Lieutenant General, and consists of a headquarters group, Marine division, air wing and logistics group. A MEF is made of anywhere between 46,000 to 90,000 marines & sailors, made up of several MEUs. The MEF is designed to sustain itself for up to 60 days in an expeditionary environment (USMC 2014).

3. Designing the Marine Force for Specific Littoral Missions

For this SEA 21B project, the focus is on a modified & reduced USMC force structure that makes use of the general organizational structure consisting of upwards of company plus-sized scalable Marine force packages (shown in Figure 29), based on their capability functions as a reduced-size force.

As such, ten different force packages were created, each with a varying force-size and composition to suit the option of fulfilling a given operational scenario and level of intensity. The ten force packages shall be discussed further in the Design Synthesis section.

The force packages provide key stakeholders with decision-making tools to select the USMC force structure and composition suited for a given operational problem. In Figure 29, the focus is on the lowest level fighting unit (encircled).

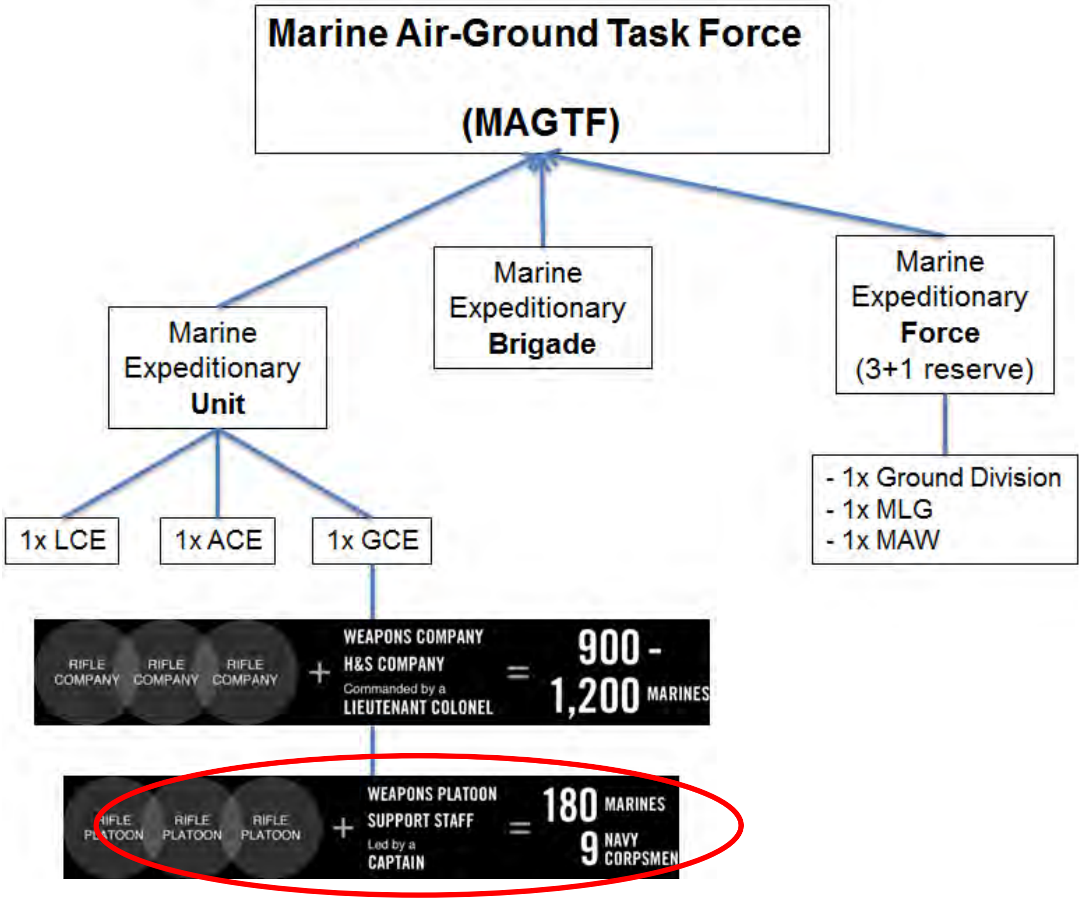


Figure 29. Overview of the Marine Air-Ground Task Force structure (from USMC 2014).

B. USMC REQUIREMENTS ANALYSIS

1. Critical Operational Issues

The five system COIs translate into requirements for the Marine group. The force packages would be created based on the requirements.

(1) COI 1: DEPLOYABLE: Can we beat the adversary to an island with our system?

The deployment of the ground forces, support and supply to the island would need to be faster than adversary.

(2) COI 2: SUSTAINABLE: Can we deliver initial troops and supplies?

The delivery of personnel and sufficient logistics in the initial deployment efforts are to be sufficient for seven of days.

(3) COI 3: DEFENDABLE: Can we defend the island?

The ground forces on the island would need to have substantial equipment and weapons to defend themselves from air and sea threats.

(4) COI 4: RELIABLE: Can we use this system on short notice?

The systems deployed are considered based on the available land area and a credible yet sufficient force size is to be placed on the island.

(5) COI 5: AFFORDABLE: Can we afford the system?

The different force packages and their costs would be considered in the tradeoff analysis.

2. Candidate Requirements

The requirements of the system to achieve the corresponding COIs are as such:

1. The system shall be deployable to the targeted location in a time limit (such as less than <72 hours) from Warning order to deployment– COI 1
2. The system shall support indefinitely the logistics requirements for men and equipment operating within the system in an A2AD environment – COI 2
3. The system shall deter adversary from occupying an island until relieved by the force commander. – COI 3
4. The system shall demonstrate defensive capabilities against credible threats (limited missile threats, , landmines, aircrafts, ships, electromagnetic warfare, and UAVs) – COI 3
5. The system shall be able to defend effectively against one company of enemy marines – COI 3
6. The system shall have the capability to detect and identify friend or foe (surface and air) up to a range commensurate with the selected package – COI 3
7. The system shall maintain communication links with USMC and USN higher HQ – COI 3
8. The system shall operate in an A2AD environment – COI 2 and 3

C. USMC FUNCTIONAL ANALYSIS

The functional decomposition (shown in Figure 30) is motivated by the system requirements and the operational activities (OA1 to OA3). Each operational activity would be fulfilled by the functions (described in green). The components (or platform) for each function would be discussed in the Design Synthesis section.

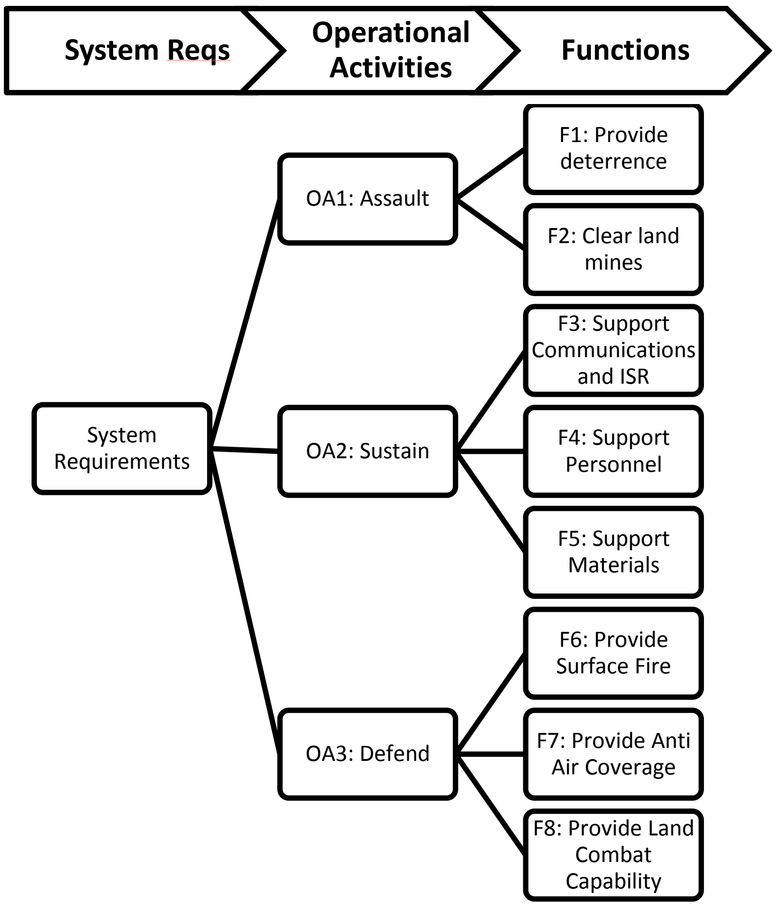


Figure 30. Functional Decomposition of Marines Forces

D. USMC DESIGN SYNTHESIS

1. Component to Function

There is no current Marines Corps force package that satisfies all of the required functions and requirements of the problem statement. There are two reasons for this

determination. The first reason is that the minimum deployable, conventional Marine unit today is the MEU, consisting of approximately 2,200 marines and sailors. For this mission the system requirement is to have a company size raid of only approximately 200 marines. The second reason is that by having the Marine land forces broken into small units, such as platoon we can meet system requirements. This partitioning gives the solution higher degrees of freedom, because almost every function could be executed by a platoon, which its mission is to fulfill these functions. For the purposes of fulfilling the requirements of the SE process, the SOS design should meet the functional decomposition of the system and the requirements. The Marines functional decomposition, as illustrated in Figure 31, would be further expanded into solution components.

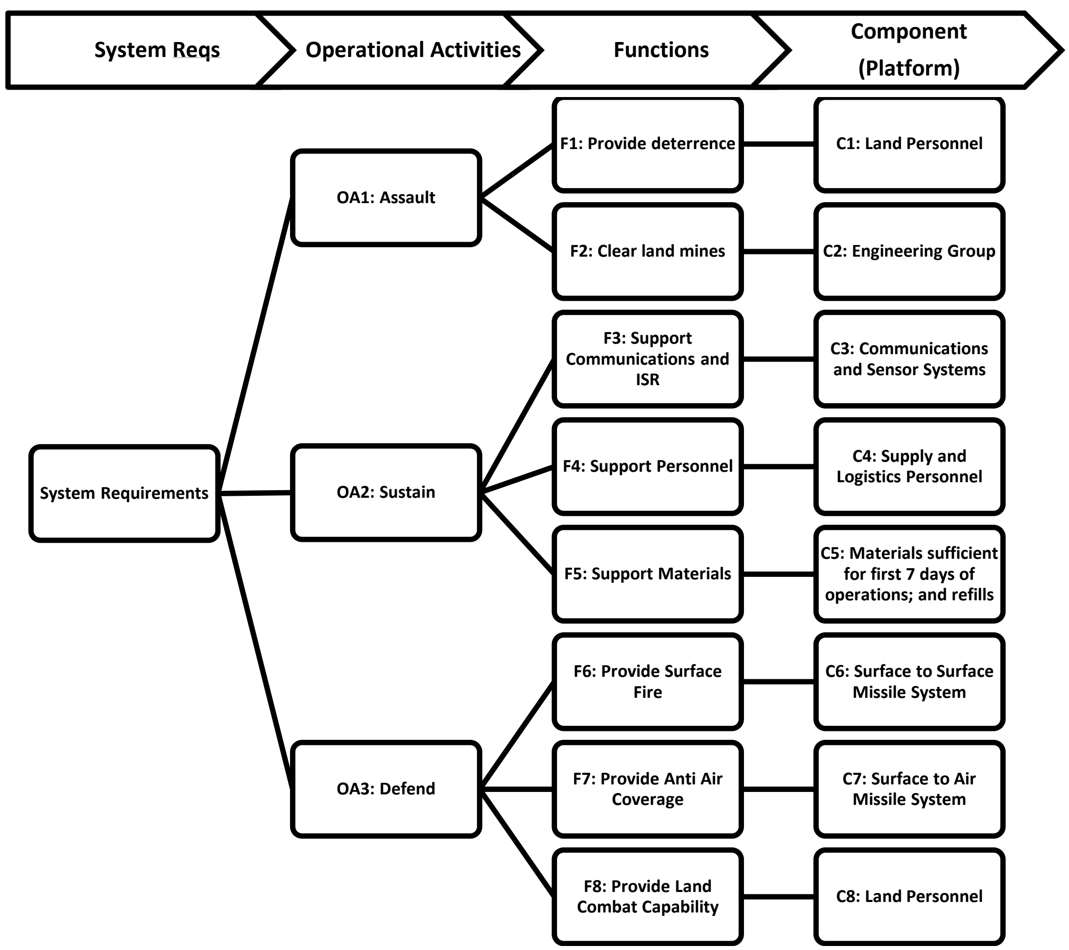


Figure 31. Functional Decomposition with Solution Components

2. Solution Space

There are two major example scenarios the Marine group used to frame the solution space: One scenario for the Spratly islands and the other based on Natuna Besar island operations. While the historical, geographic, and cultural considerations related to these different islands are significant, there are two major differences between the scenarios. The first major difference for analytical purpose is the size of the islands. The largest of the Spratly Islands has an area of 0.445 square kilometers, whereas Natuna Besar is vast by comparison at 1720 square kilometers. The second major difference is the location of the contested littorals relative to U.S. and allied forward operating bases in the Southeast Asia AOR.

Evaluating force packages for their defensive capabilities, we designed three threat scenarios. In all three, the U.S. goal was to put troops on the ground (after clearing the area), sustain, and adopt a defensive posture to hold out against possible bombardment and amphibious assault. Each scenario evaluated distinct Red force threat environment levels – low, medium and high. In all environments, the landing and occupation are assumed to be unopposed; however allowances were made for a variety of potential threats. A low threat level refers to a completely unopposed occupation mission. The medium threat level requires the Blue force to have additional defense against attacks by manned or unmanned aircraft sorties of varying size as well as non-precision surface threats. Finally, the high threat level requires the Blue force to implement defensive preparations for cruise missile attacks against the friendly Marine force.

The breakdown of this solution space is presented in Table 5. Note that it is possible to create small platoons to fulfill each functional need. Force package options are listed in the far right columns as outputs from each scenario, threat level, and functional input combination:

Table 5. Marine Force Packages

Scenario	COAs	Threat	Defence/deterrence					Supply	ISR
			Land Mines	Anti-air	Anti-ship	Anti-UAVs	Landing Force		
Spratly Islands (Baseline)	**COA 1**	Low	Engineering Group & tools	-	D1 Trenches	-	F1 Rifle company (96) Logistics team (22) Total (118)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C1 Package 1) JLENS
	COA 2		Engineering Group & tools	-	D1 Mobile Concrete Igloos	-	F1 Rifle company (96) Logistics team (22) Total (118)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C2 Package 1) Giraffe AMB 2) Quadcopter
	COA 3	Medium	Engineering Group & tools	D2 Patriot (x1)	D2 NSM (x1)	D2 Avenger/ Laser (x1)	F2 Rifle company (114) Logistics team (22) Total (136)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C3 Package 1) AN/TPS-80 2) AN/MPQ-53 3) Predator 4) REMUS 600/6000
	COA 4		Engineering Group & tools	D2 Patriot (x1)	D2 NSM (x1)	D2 Avenger/ Laser (x1)	F2 Rifle company (114) Logistics team (22) Total (136)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C4 Package 1) AN/TPS-80 2) AN/MPQ-53 3) RQ-7 Shadow 4) Quadcopter 5) REMUS 600/6000
	COA 5		Engineering Group & tools	D2 Patriot (x1)	D2 NSM (x1)	-	F2 Rifle company (114) Logistics team (22) Total (136)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C4 Package 1) AN/TPS-80 2) AN/MPQ-53 3) RQ-7 Shadow 4) Quadcopter 5) REMUS 600/6000
	COA 6	High	Engineering Group & tools	D2 Patriot (x1)	D2 NSM (x1)	D2 Avenger/ Laser (x1)	F2 Rifle company (114) Logistics team (22) Total (136)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C3 Package 1) AN/TPS-80 2) AN/MPQ-53 3) Predator 4) REMUS 600/6000
Natuna Besar (Higher Level)	**COA 7**	Low	Engineering Group & tools	-	D1 Trenches	-	F3 Rifle company (114) Logistics team (54) Total (168)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C1 Package 1) JLENS
	COA 8	High	Engineering Group & tools	D2 Patriot (x3)	D2 NSM (x1)	D2 Avenger/ Laser (x1)	F4 Rifle company (200) Logistics team (54) Total (254)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C3 Package 1) AN/TPS-80 2) AN/MPQ-53 3) Predator 4) REMUS 600/6000
	COA 9	Medium	Engineering Group & tools	D2 Patriot (x2)	D2 NSM (x1)	D2 Avenger/ Laser (x1)	F4 Rifle company (200) Logistics team (54) Total (254)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C3 Package 1) AN/TPS-80 2) AN/MPQ-53 3) Predator 4) REMUS 600/6000
	COA 10	Medium	Engineering Group & tools	D2 Patriot (x2)	D2 NSM (x1)	-	F4 Rifle company (200) Logistics team (54) Total (254)	Water, Food, Fuel, Medical supplies, generators, vehicles, handheld and vehicular comms (7 days)	C4 Package 1) AN/TPS-80 2) AN/MPQ-53 3) RQ-7 Shadow 4) Quadcopter 5) REMUS 600/6000

The solutions for each function were chosen among those functions that meet the feasibility requirement. Ten force packages were created as a result of the available options, and the approximate weight of each was calculated, in order to meet the naval

deployment requirements. Force packages were then compared to one another for each MOE, in order to determine the tradeoffs resulting from package selection (more on that in Section 4 of this chapter). The solutions for the individual components are:

a. Land Forces

The land forces that are to be used as a deterrent to the Red force consist of a rifle company and a logistics team. As the area of the Spratly Islands is limited, the number of personnel is restricted. The current rifle company in the USMC organization is 183 men and it does not include the logistics team. Hence the deterrence forces would be customized for the purpose of deployment to vastly different locations such as one of the many tiny Spratly Islands in contrast to an expansive island such as Natuna Besar. For modeling purposes, the land force package selection is based on the threat level and size of the island selected.

Land forces composition L1 and L2 are applied to the Spratly Islands as shown in Table 6. As the surface area of the largest island is small, we would limit the logistics team to a minimum. The truck squad, maintenance squad, and engineer platoon are omitted. The logistics headquarters is not required for a small team of logistics personnel and can be replaced with one of the men in the company headquarters. For a low threat level, the air defense squad is omitted from the L1 composition.

Land forces composition L3 and L4 are applied to Natuna Besar as shown in Table 7. As Natuna Besar has a much larger land area, the number of personnel deployed is not restricted. However, for increasing threat levels we will require increasing force size to act as a deterrent. For a low threat level, there would be one rifle platoon, but for medium or high threat levels, there would be three rifle platoons. Both L3 and L4 would have an air defense squad.

Table 6. Land Forces for Spratly Islands

Scenario: Spratly Islands			
Composition of Personnel (L1)	**Low Threat**	**Composition of Personnel (L2)**	**Medium/High Threat**
1 x rifle platoon	43	1 x rifle platoon	43
1 x weapons platoon	47	1 x weapons platoon	47
1 x air defence squad	0	1 x air defence squad	18
Company headquarters	6	Company headquarters	6
Rifle company total	96	Rifle company total	114
1 x engineer platoon	0	1 x engineer platoon	0
1 x medical squad	4	1 x medical squad	4
1 x truck squad	0	1 x truck squad	0
1 x landing support squad	12	1 x landing support squad	12
1 x maintenance squad	0	1 x maintenance squad	0
1 x supply squad (food/water)	6	1 x supply squad (food/water)	6
Logistics headquarters	0	Logistics headquarters	0
Logistics total	22	Logistics total	22
Total Personnel	118	Total Personnel	136

Table 7. Land Forces for Natuna Besar

Scenario: Natuna Besar			
Composition of Personnel (L3)	**Low Threat**	**Composition of Personnel (L4)**	**Medium/High Threat**
1 x rifle platoon	43	3 x rifle platoon	129
1 x weapons platoon	47	1 x weapons platoon	47
1 x air defence squad	18	1 x air defence squad	18
Company headquarters	6	Company headquarters	6
Rifle company total	114	Rifle company total	200
1 x engineer platoon	12	1 x engineer platoon	12
1 x medical squad	4	1 x medical squad	4
1 x truck squad	12	1 x truck squad	12
1 x landing support squad	12	1 x landing support squad	12
1 x maintenance squad	5	1 x maintenance squad	5
1 x supply squad (food/water)	6	1 x supply squad (food/water)	6
Logistics headquarters	3	Logistics headquarters	3
Logistics total	54	Logistics total	54
Total Personnel	168	Total Personnel	254

b. Defense System

(1) Surface Defense

From the functional decomposition, F6 corresponds to providing surface fire, which is a component of OA3: Defend. The major threat the Marines are addressing is the Chinese small combatant ship. Type 022, equipped with Hongniao missiles. For the low threat level, we offer two solutions, which are both defensive in nature: Trenches and Mobile Concrete Igloos (MCI).

Creating quality trenches is a relatively cheap process, requires very few types of tools, and allows Marines to rapidly access defensive positions that greatly reduce their exposure and therefore vulnerability to kinetic surface attacks.

Mobile Concrete Igloos are currently in use as a means of both military and civilian defense in locations such as Israel (Stahl 2008). MCIs protect those inside from fragmentation and even some direct impacts from rocket attacks and other ballistic projectiles. Each igloo can serve up to 30 people (so the amphibious force would deliver several of them in order to protect a platoon). Each unit weighs 11,023 pounds (>5 tons) ("Modular" n.d.) and costs $36,000 (U.S.) (Stahl 2008).

For the medium and high threat level, the mitigation of the surface threat is a combination of defense and offense. Defense hinges on actively intercepting threats like the incoming *Hongniao* missiles, while offense involves attacks against the Type 022 in order to eliminate the threat.

The Patriot Missile is the preferred solution for active defense. It serves both as anti-missile defense and anti-air defense. The reason the Patriot was chosen is due to its long range, which was deemed necessary for attacking threats such as the J-15, and because of its ability to engage both aircraft and other missiles. Specifications for the Patriot can be found in Appendix C.

The Naval Strike Missile (NSM) is the preferred solution for attacking surface threats. It is Norwegian anti-surface, sea-skimming, subsonic missile that can be launched from land. It was chosen because it has the best tradeoff of sufficient large range and low weight. The characteristics of the NSM can be found in Appendix C at the end of this report.

(2) Air Defense:

Against Swarms of UAVs or even single UAVs the Patriot is not an efficient nor cost effective solution. The high cost and weight of each Patriot round presents a challenge in warranting its legitimate use against relatively cheap UAV targets.

The preferred solution for a UAV threat is the Avenger (AN/TWQ-1) by Boeing, which is a highly mobile short-range anti-air system. The main armament of the Avenger is the Stinger, which is a cheap ($38,000 per missile), short-range (8 kilometers) infrared surface-to-air missile. The Avenger can carry between four and eight Stingers. Specifications for the Avenger can be found in Appendix C.

A different possible system against the UAV threat is a truck mounted Directed Energy Weapon (DEW), which can be described as laser against UAV.

The primary advantage of a DEW is that each shot of the laser should be much cheaper than a missile, and it can work as long as it has source of power, compared to the consumable missiles.

For land forces, Boeing has conducted DEW testing using an Avenger assembly, and has successfully shot down a UAV in a 2008 field test (Marks 2009). The system is not currently in operational forces, but it is completely plausible that such units would be deployed operationally in the 2025–2030 timeframe. In that event, we assume in the worst-case scenario it has the characteristics of a Stinger Avenger, and therefore we consider them interchangeably in this thesis report.

c. Logistics

The Marines logistics subsystem consists of the fixed assets and the supplies, which would be re-supplied after seven days of operation. The fixed assets include generators, transport vehicles, handheld and vehicular communication systems, and tools for an engineering group, while the supplies (consumables) include water, food, medical supplies, and fuel for generators and vehicles.

The amount of water, food and medical supplies for seven days is estimated based on existing Marine Corps logistic models provided by Operations Department in Naval

Postgraduate School. The summarized costs are stated in Appendix C Communications and ISR.

The Marines land forces possess handheld and vehicular communications for both short and long range communications. Alternative communications solutions mirror the Communications system design in Section H of Army/Air Force solutions.

As for the ISR solutions, the Marines would provide specific systems based on three threat levels (low, medium, and high). The types of systems include:

- Long-range radars (AN/TPS-80, JLENS)
- Medium-range radars (Giraffe AMB)
- Detection radar for Patriot missile (AN/MPQ-53)
- Long-range optical sensors (JLENS, Predator)
- Short-range optical sensors (RQ-7 Shadow, Quadcopter)
- Unmanned underwater vehicles (REMUS 600/6000)

The following ISR equipment items are shortlisted based on factors such as weather conditions and detection range. The C-band (4-8GHz) and S-band (2-4GHz) are selected as these frequency ranges are less prone to weather conditions. South China Sea, where Spratly Islands are located, experiences heavy rainfall and strong winds during the monsoon seasons. Another scenario for consideration is the Gotland Island in Baltic Sea. The Baltic Sea may have moderate rainfall but fog is common in spring and early summer. The rainfall and fog can greatly attenuate frequencies above 10 GHz, requiring the primary use of C-band and S-band. The detection ranges vary largely because there is a need to include low cost alternatives to the different packages at the same time.

Table 8. List of ISR Equipment and Specifications

Equipment	Function	Speed (mph)	Horiz Range (mi)	Vert Range (kft)	Frequency of operation /Optics	Weight (lbs)
JLENS	Over-The-Horizon surveillance	-	340	15	FO link	7,000
Giraffe AMB	Coastal surveillance	-	62	60	5.4 to 5.9 GHz (C-band)	550
AN/TPS-80	Air surveillance	-	160	40	2–4 GHz (S-band)	8500
AN/MPQ-53	Surface-to-air missile assisting radar	-	105	25	4-8GHz (C band)	5,667
Predator	Surveillance with optical sensors, with 2 hellfire missiles	300	770	25	EO/IR, Thermal, C-band link	2250
RQ-7 Shadow	Surveillance with optical sensors	103	68	15	EO/IR, C-band link	375
Quadcopter	Surveillance with optical sensors	31	2	1	-	3.1
REMUS 600/6000	Underwater surveillance	4kts	up to 24 hours	- 1500/6000m	9 - 16 KHz	530

Table 9 provides a matrix for ease of decision making when selecting ISR packages according to the scenario threat level and the size of the land area selected for occupation by Marine forces.

Table 9. ISR Packages and Their Costs

ISR Package	Package Details	Qty	Unit Cost ($M)	Total Costs ($M)	Package Cost ($M)
C1	1) JLENS	1	11.9	11.9	11.9
C2	1) Giraffe AMB	2	7.8	15.6	15.63
	2) Quadcopter	15	0.002	0.03	
C3	1) AN/TPS-80	1	50	50	93
	2) AN/MPQ-53	1	3	3	
	3) Predator	4	5	20	
	4) REMUS 600/6000	4	5	20	
C4	1) AN/TPS-80	1	50	50	104.03
	2) AN/MPQ-53	1	3	3	
	3) RQ-7 Shadow	8	3.875	31	
	4) Quadcopter	15	0.002	0.03	
	5) REMUS 600/6000	4	5	20	

3. Modeling the Marine Corps Design

a. Defense System

The Marine defense is divided into three categories:

1. Land defense
2. Surface (sea) defense
3. Air-defense

The land defense is the natural state of an entrenched Marine rifle company. We assumed that the land battle will not be the first nor second choice of the adversary to kinetically attack the island. We assess adversaries will likely opt for battling for sea control or air superiority to maintain the A2AD environment well before selecting amphibious assault. Apart from the immediately high numerical casualties assured through those operations, there is also the fact that in order to successfully deploy land forces the adversary must negate A2AD measures implemented by Blue forces. It is much easier to surround, isolate, and if necessary bombard the island and eliminate the Blue force through missile attack or bombs than by landing assault forces. For these reasons, the group has only modeled the surface and air battle.

We can compare between the different work packages by scoring them for how much they are able to defend the island, based on the modeling results that are described in the modeling sections.

For each type of threat (air or surface), the group assigned point scoring according to thresholds of performance. No points were awarded if the system was completely unable to defend itself. One point was awarded if the system was unable to win a plausible battle but did present some capabilities for threatening the adversary. Two points if the system was able to defeat medium and low-level threats. Finally, three points were awarded if the system was assessed as likely able to win a battle against any threat.

The low threat force packages have passive defense systems like concrete igloos. They are important for defense in case the threat level was incorrectly evaluated, but the score would be zero points regardless due to the inability to threaten an adversary. Table 10 presents the assessed force packages and their scores.

Table 10. Force Packages and Scores

Force Packages/Battle	Surface defense	Air defense	Total Score
1	0	0	0
2	0	0	0
3	2	1	3
4	2	1	3
5	2	1	3
6	2	1	3
7	0	0	0
8	3	3	6
9	2	3	5
10	2	3	5

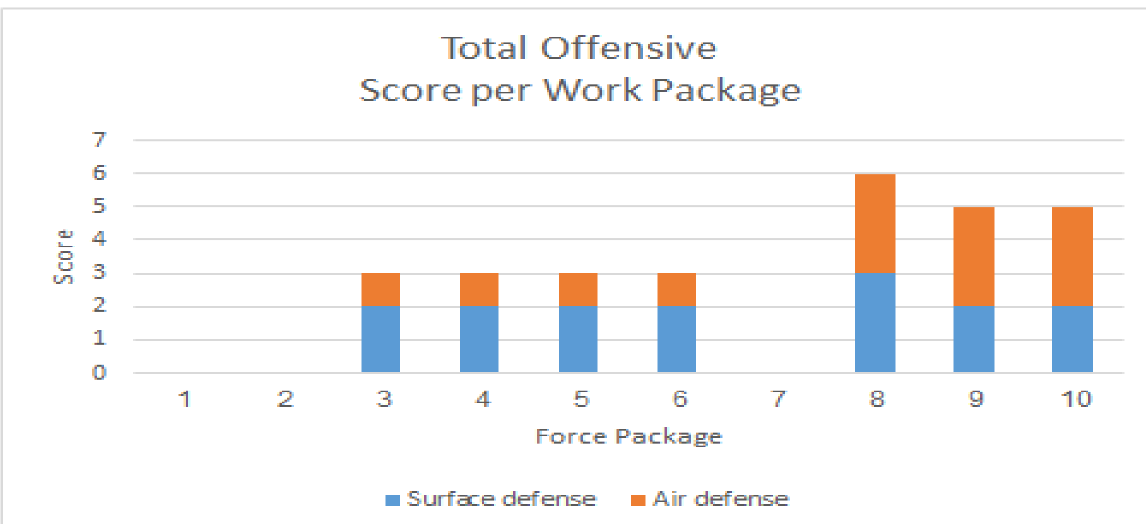


Figure 32. Score per Work Package

Force Package 8 is the most suitable for a high threat environment, according to Figure 32, while force packages 1, 2 and 7 could only be considered suitable for low-

level threats, because none of those packages included weapons for counter-attacking enemy threat platforms.

b. ISR Model

From Table 8 and Table 9, four ISR hardware packages were designed based on theoretical detection (radar or optical) capabilities for each of the ten Marine force packages.

Based on the theoretical ISR packages, particular solutions within force packages were modeled as a means to test whether the solution were feasible. If the results were positive, then we feel confident in our ability to assume that the rest of the solutions within the four packages are feasible.

In this model, four UAVs (RQ-7 Shadow) are utilized. Three UAVs programmed to patrol an area of five nautical miles from the target island while one of the UAVs is programmed to hover around the target island where the Marine force is defending. The model was created with Map-Aware Non-uniform Automata (MANA™) simulations program. MANA ™ is an agent based simulator that allows for very detailed modeling of various military platforms. More detailed information on MANA and UAV search models is found in chapter XI section 6.

The stationary UAV acts as the final line of detectability in scenarios where the Red force's ships are able to bypass the three of the UAVs on randomized search patterns.

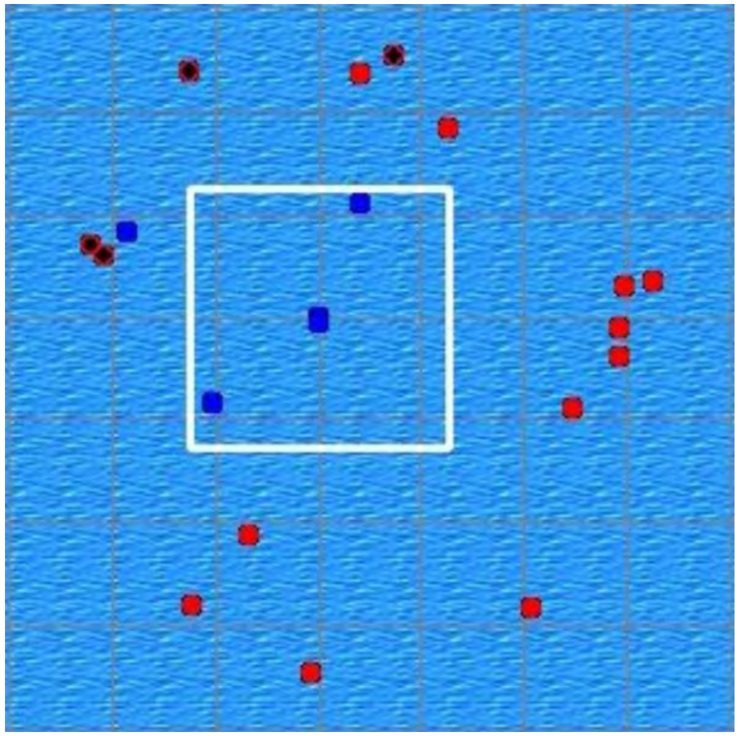


Figure 33. Four UAVs (One Stationary Over Defended Island)

In the model shown in Figure 33, the three UAVs shown as blue dots on randomized (optical) search patrol were able to detect all fifteen incoming hostile/ enemy ships shown with red dots coming towards an island perimeter depicted the white square. With this detection, the higher-level USMC authority can be alerted for possible counter-offensive or defensive actions; and if the Blue Force's capabilities are limited in the neutralizing the threat, the USN can be alerted to taking out the incoming threats.

4. USMC System Tradeoff Analysis

As are all systems, there is no one-size fits all solution. Due to system tradeoffs, ten different USMC force packages or COAs were selected in terms of counter-offensive scoring and the results were presented in the previous sections shown. This enables a stakeholder to make decisions on the various force packages that best fit an operational scenario (e.g., operational scope, logistics available, enemy size).

a. Weight Analysis

The Marines land forces and systems are brought to the island via the USN ships or USAF aircraft, hence the weight analysis is crucial when determining which vessels and/or delivery aircraft are utilized.

The heaviest force packages (COAs for this exercise) are not surprisingly the two (COAs 6 and 8) catered for the highest threat level in each of the two scenarios. COA 3, which has the same defense systems and land forces as COA 6, is tied with COA 6 for the second-heaviest force package.

The lowest weight options for each scenario are COAs 1 and 7, respectively, but they are designed for lower threat levels.

b. Cost Analysis

Each subsystem in the solution space has a cost attached to it. The total cost of each COA includes the price of the subsystems themselves (e.g. Patriot battery), the spares cost if needed (e.g., Patriot missiles) based on the Salvo-Equations Model and the logistics cost for a 7 days deployment (e.g., fuel) based on the Consumption Model. The specific costs for the subsystems and the spares are stated in Appendix C, while the total cost for each COA is summarized in Table 11. The logistics costs are stated in Appendix C.

COA 8 is not only the heaviest, it also (again, not surprisingly) ranked the highest in costs. The cost of COA 6 is, however, lower than COA 4 or 5 which are meant for medium threat levels. The reason is mainly due to the fact that the unmanned aerial vehicle (UAV) Predator RQ-1 is used in COA 6 while Shadow RQ-7 is used in COA 4 and 5. We required more RQ-7s to meet the required detection range but the costs of both UAVs are very close ($3.875M for RQ-7 and $4M for RQ-1), resulting in the slightly higher costs in COA 4 and 5.

COAs 1 and 7 have the lowest costs but they are designed for lower threat levels.

Table 11. Weights and Costs for Ten Marine COAs

Scenario	COAs	Threat Level	Weight (lbs)	Cost ($)
Spratly Islands (Baseline)	COA 1	Low	452,841.25	$34.8M
	COA 2		515,646.20	$38.688M
	COA 3	Medium	603,556.80	$162.492M
	COA 4		587,732.80	$173.422M
	COA 5		558,197.35	$172.77M
	COA 6	High	603,556.80	$162.492M
Natuna Besar (Higher Level)	COA 7	Low	494,258.50	$42.1M
	COA 8	High	737,140.80	$240.824M
	COA 9	Medium	715,750.80	$209.732M
	COA 10		690,036.80	$220.11M

From Table 11, the wide range in costs from $3.8M to $240M require careful consideration for a decision maker, but also provides a large spectrum of cost options.

c. *Defendability Analysis*

The defendability score is aggregated from four aspects (defendability against surface threats, defendability against air threats, detection range for surface threats, detection range for air threats), each having equal weightage of 0.25.

The score is derived from passive and active defense capabilities. Passive defense is the detection of threats while active defense allow counter-attack capabilities from the island. The scores could be found in Table 12. We can obtain from the table that a score of 0 can deal with a low level of threat while a score of more than 5 would suffice against higher threat levels. The highest score that could be achieved is 8.4, which would suffice against the highest threat level in the Natuna Besar scenario.

COAs 1, 2, and 7, which are designed for the low-level threats, have no air or surface defenses, therefore their total defendability scores are the lowest.

COAs 6 and 8 have the highest defendability scores in the Spratly islands and Natuna Besar scenarios, respectively.

We ranked the scores in the final ranking, where rank of 1 is the best COA.

Table 12. Defendability Scores for Ten Marine COAs

Scenario	COAs	Threat Level	Weighted Scores					Final Ranking (1 being the best)
			Salvo Equations for Defense		Detection Ranges		Total	
			Surface	Air	Surface	Air		
Spratly Islands (Baseline)	COA 1	Low	0.00	0.00	0.11	0.25	0.36	5
	COA 2		0.00	0.00	0.00	0.00	0.00	6
	COA 3	Medium	0.17	0.08	0.25	0.09	0.59	3
	COA 4		0.17	0.08	0.02	0.09	0.36	5
	COA 5		0.17	0.08	0.02	0.09	0.36	5
	COA 6	High	0.17	0.08	0.25	0.09	0.59	3
Natuna Besar (Higher Level)	COA 7	Low	0.00	0.00	0.11	0.25	0.36	5
	COA 8	High	0.25	0.25	0.25	0.09	0.84	1
	COA 9	Medium	0.17	0.25	0.25	0.09	0.75	2
	COA 10		0.17	0.25	0.02	0.09	0.53	4

d. *Tradeoff Analysis (Weight, Cost and Defendability)*

The most cost effective option for Spratly Islands is COA 6 as it has the highest defendability score while costing $10M less than other COAs for the same scenario. The tradeoff is that COA 6 weighs 46,000 pounds more. Depending on the transport vessel used, this additional weight may not pose a large logistic problem.

COA 9 is the most cost and weight efficient for Natuna Besar scenario. It costs $31M less and weighs 22,000 pounds less than COA 6. Even though COA 9 does not have the highest defendability score, its score of 7.55 is still high considering that the highest is 8.38.

The costs and defendability analyses for the Marine forces mentioned in the sections above serve only as a baseline for decision-making. Depending on the actual operational scenario, the stakeholder will more likely have to scale the solutions (COAs) up or down to fit the overall demands (defendability) or constraints (costs).

The Marine force packages are part of the littoral mission that includes COAs from the USN and the Army/ Air Force groups; hence the overall score of the integrated solutions would be based on factors of defendability, costs, weight, and speed. The score

would provide the stakeholders a more thorough overview and practical analysis of the solutions.

E. USMC SYSTEM CONCLUSION

We have a variety of solutions for the deployment of Marine land troops on an island for deterrence purposes. These solutions meet all our functional requirements, which were discussed in the Functional Analysis section.

The costs of COAs range from $34M to $240M while the weight of COAs range from 452,000 pounds to 737,000 pounds. The defendability ranges from a score of 0 to 8.38, which provide options for low, medium and high threat levels.

On one hand, we have the low cost, lightweight solution but low defendability against medium or high threats. On the other hand, the solutions that provide substantial defense capability require higher costs (a maximum of seven times more than the COA with lowest cost), heavier items and more personnel.

Most importantly with all the baseline COAs presented, the stakeholder as the decision-maker can choose and modify (scale up or down) the COA that best fits the operational requirements and constraints.

X. U.S. ARMY AND AIR FORCE SOLUTIONS

A. ARMY AMPHIBIOUS HISTORY

The U.S. Army conducts forced entry expeditionary operations of Air Assault, Airborne landings, and Amphibious Assaults using a mix of highly mobile and deployable units. The overriding issues that the Army must contend with in effecting the employment of current forces are the physical effects of time and distance. Highly deployable forces such as the XVIII Airborne Corps in Fort Bragg North Carolina are unique in their capability to project combat power anywhere in the world in a short amount of time. The XVIII Airborne Corps' 82nd Airborne Division Ready Brigade is on notice to deploy anywhere in the world for combat operations in under 18 hours. This rapid deployment comes at a price. The more deployable a force is, the lighter that force must become in order to fit within the constraints of available Air Force platforms such as the C-130, C-17, and C-5 military transport airplanes. Being light requires the sacrifice of unit vehicles for mobility, armor for protection, combat loading for extended operations, and organic long range weapon systems for offensive and defensive missions.

These sacrifices in capability are currently necessary in achieving a crucial time advantage over potential adversaries. Airborne forces have the niche capability of rapidly deploying from home base(s) to critical infrastructure nodes such as seaports and airfields in an OPAREA. Airborne forces secure these key nodes in order to facilitate the follow-on deployment of heavier and more lethal ground forces.

B. THREAT TO ARMY EXPEDITIONARY OPERATIONS

The short history of American Expeditionary operations and how the U.S. Army participated begins in the First World War with the Army's deployment via the safety of French Ports. Heavy supplies and equipment were transported from CONUS to the European theater to the relative safety of a friendly theater seaport. In WW II, the French Ports were not available. However, the proximity of Great Britain to Nazi held France made an amphibious landing feasible onto the beachheads of Normandy. Amphibious

landings were also the preferred tactic in the Pacific theater. The defending Japanese forces had no capability beyond limited fighter aircraft to hold attacking U.S. amphibious forces at bay. Vietnam introduced advances air power where the U.S. could deploy troops quickly over long distances via strategic air transport. During the first Gulf War, the U.S. deployed its forces over several months via both air and sea in order to build up the requisite combat power necessary to destroy Saddam Hussein's forces in Kuwait. In each preceding instance, U.S. land forces deployed via sea where it took a considerable amount of time to establish theater combat power.

Airborne troop deployments against a mechanized adversary such as Saddam's armored Republican Guard units carried risks in terms of force factors of light infantry versus a more lethal mechanized force. The 82nd Airborne was deployed as a tripwire force against Saddam pushing beyond Kuwait into Saudi Arabia. Had Saddam made the force calculations he would have found that he possessed a numerically superior force to the lighter American unit. Fortunately for the U.S., Saddam's forces held their positions in Kuwait allowing the U.S. enough time to deploy heavier forces to the Gulf (Matsumura 2000).

Today the threat to rapidly deployable Army Airborne forces has grown beyond the borders of the area of operations (AO). As mentioned in this report, current A2AD capabilities threaten ships and aircraft delivering land forces to their objectives. This chapter examines a few technologies in the testing and evaluation phase that the group believes the U.S. Army needs to consider integrating into an A2AD penetration concept.

C. USA/USAF CONCEPT OF OPERATIONS

The Army and Air Force CONOPS include: (1) initial delivery of troops and materials, as a form of setting up the base for further sustained operations; (2) sustaining the operations through resupply of troops and materials; and (3) defending the operating base from incoming threats, both conventional and unconventional. Typically, the nature of operations of Army and Air Force components lead to a sub-division of ground operations (for the Army), and aerial operations (for the Air Force).

D. USA/USAF REQUIREMENTS ANALYSIS

1. Army/Air Force Specific Requirements

The Air Force (due to the nature of their operations) will be focused on swift and rapid delivery of troops and supplies. Complementary by the manpower supplied by the Army, the various functions of the Army / Air Force is to ensure that the integration of the mission requirements are met and accomplished according to the various COAs being charted out. The functional analysis below is deliberated in the next section.

E. USA/USAF FUNCTIONAL ANALYSIS

1. Functions

The Army/Air Force group has three primary functions:

1. To deliver initial supply of troops and materials, if required
2. To sustain the ground operations through resupply of personnel and materials, if required
3. To defend the OPAREA through aerial means, against possible hostile incursion that may disrupt Blue force's operations

2. Sub functions

All three functions are to be analyzed and performed in both naval denial and aerial denial environments.

F. USA/USAF DESIGN SYNTHESIS

1. Component to Function—Army

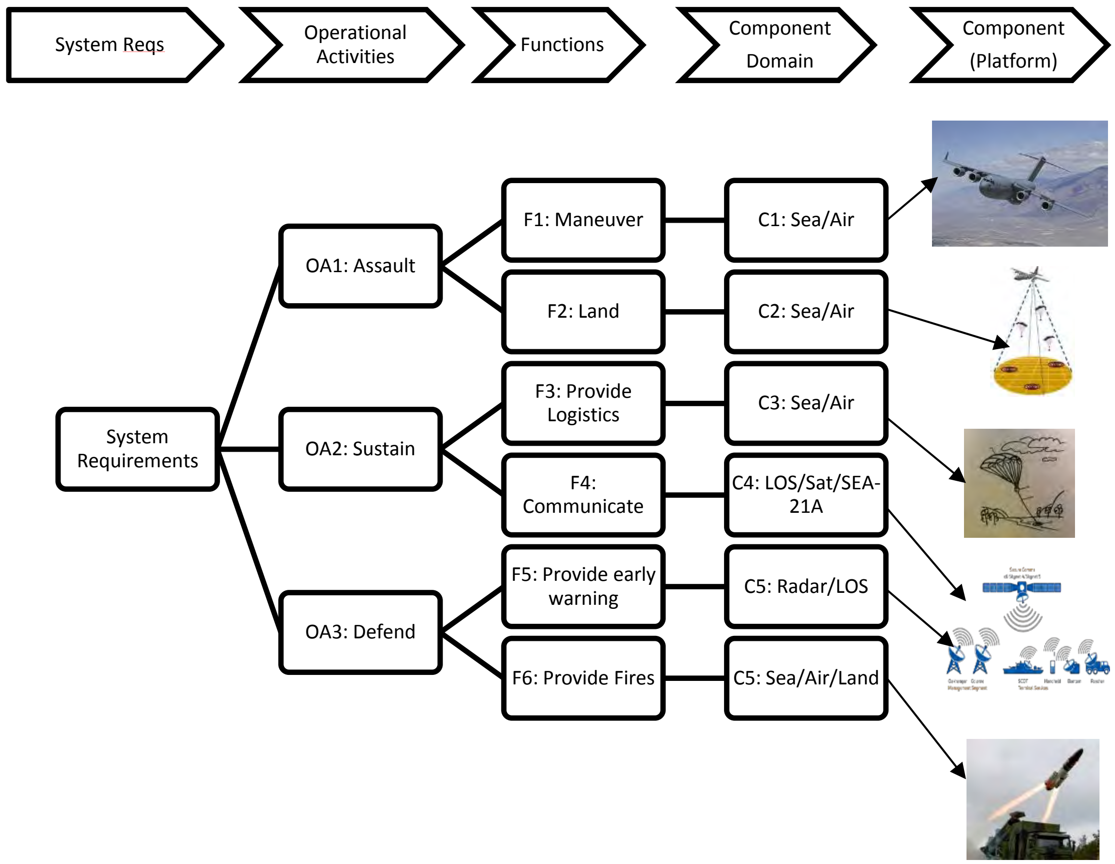


Figure 34. Concept System (Photos in Image from Jane's 2015)

The current force packages for the Army / Air Force will be centered on swift and rapid delivery. Hence, delivery, sustenance and defense will be the core supplementary mission for the Army / Air Force components of this Joint Operations. Coupled with the Marine Corps requirements of the troop size (approximately 200 marines) for efficient operations, the fleet requirements will be sufficiently designed to meet the mission requirements based on the functional analysis. In this analysis, the Army will be the main manpower component to ensure that the operational functions on the ground can be carried out effectively upon successful delivery by the Air Force component. Figure 34 represents the functional decomposition of the joint Army and Air Force component.

2. Component to Function—Air Force

The Air Force morphological options are detailed in Tables 13–17.

a. Operational Analysis 1—Delivery

Table 13. Delivery Morphological Box

Prepared Airfield	Austere Airfield	Unable to Support Landing Aircraft	Unable to Support Aircraft & Mined (*)
• C-17 • C-130 • Vertical Lift	• C-130 • Vertical Lift • High Speed AFSB	• Vertical Lift • High Speed AFSB • JPADS	• (3) High Speed AFSB • (2) JPADS - E • (1) Sacrificial Afloat Staging Barge

* Number indicates sequence of operations. Entire process may be preceded by rapid mine clearing techniques.

b. Operational Analysis—Sustain (Permissive and Denied Environments)

Table 14. Sea Sustainment Morphological Box

Sustain by Sea	
Permissive	Denied
• Large Cargo Ship • Medium Cargo Ship • JHSV • Go-Fast • Semi-Sub • Indigenous Entrepreneurs	• Go-Fast • Semi-Sub • Indigenous Entrepreneurs

Table 15. Air Sustainment Morphological Box

Sustain by Air	
Permissive	Denied
• C-17 • C-130 • Vertical Lift	• C-17 • C-130 • Vertical Lift

Sustain by Air	
Permissive	Denied
• JPADS	• JPADS • Fulton Recovery System

c. Operational Analysis 3—Defense

Table 16. Defend (Against Conventional Threats)

Surface Threats	Air Threats
• Automated Detection & Tracking Systems • ASM in a Box • Combat Air Patrol	• Automated Detection & Tracking Systems • Combat Air Patrol • SAM in a Box

Table 17. Defend (Against C4ISR)

Permissive	Denied
• Current Methods • Low Altitude Balloon • Anti-Jam Techniques • Network Optional Communications	• Low Altitude Balloon • Anti-Jam Techniques • Network Optional Communications

Thus, there are a multitude of available technologies and platforms that cater to many of the anticipated operational scenarios during conduct of the missions.

G. MODELING THE USA/USAF DESIGN

1. Deploy the System: COI 1

The optimal method to deploy any of the desired systems is to employ the large capacity aircraft so that delivery can be optimized within the minimal number of sorties. However, economies of scale ought to be taken into considerations. A C-17 transporter aircraft can efficiently deliver large-size assets including Patriot missile systems for rapid deployment into the OPAREA. Once the aircraft had landed, then the ground forces can rapidly set up the area or point defense and operations can commence soon after.

Prior to that, the considerations of the deployment of air force options needed to be weighted consciously. The infrastructure allowed within the OPAREA will be a key consideration for the method of delivery. If an established and secured airfield is available, then transport aircraft can be utilized to deliver large cargo in small amount of time frames. If a landing airstrip is unavailable due to lack of land, then the Osprey V-22 vertical lift option can be considered as an alternative. Lastly, if both of the aforementioned options are unavailable, the USAF has at her disposal highly accurate GPS steering devices for dedicated airdrops, such as the Joint Precision Airdrop System (JPADS). However, the JPADS would not be capable of delivering as large a capacity compared to conventional transport aircraft.

2. Deliver initial Troops and Supplies: COI 2

The methods of delivering initial troops and supplies can be further deconstructed into transportation of personnel/materiel and reinforcement of personnel/ materiel. Analysis on the reinforcement of personnel / materiel is further broken down into sub-divisions of reinforcements via surface channels, and reinforcements via air channels. For the purpose of generality, the methodologies described below would be applicable to both initial delivery and subsequent resupplies of personnel and materiel.

For transportation via air channels, the typical U.S. assets to be used are the C-17s, and the C-130Js, that are capable of transporting large numbers of personnel and critical ground assets. A slightly non-conventional approach is employed to scan for other viable measures for initial delivery, and the vertical lift platform V-22 was also

identified as a plausible means of transportation. The use of the V-22 eliminates the need for a dedicated runway with which conventional aircraft requires for takeoff and landing.

a. Denial of Airspace or Air Superiority

The U.S. Air Force's delivery of the initial supplies and subsequent resupply missions could be completely jeopardized in denied aerial environments where the adversaries could form a protective umbrella around the AO. The umbrella would be intended to deny the U.S. Army from using free usage of airspace to conduct air drops of troops or supplies.

For transportation via sea / surface channels, the straightforward ingress option would be via the JHSV, which are capable of rapid intra-theater transport of medium-sized cargo payloads. This rapid redeployment of forces and slick movement among the many islands in the OPAREA provide the BLUE FORCE with a quick responsive option during the deploy and sustain phases.

b. Denial in Naval Environments

In denied sea surface environments, whereby the ingress routes towards the island are assumed to be laid with sea mines. Minefields could deny the U.S. Army the ability to speedily unload its troops off the coast of the AO.

Comparatively, to minimize potential losses of Blue force assets, the much preferred option would be to resupply via the air channel.

3. Penetrate A2AD with the System: COI 3

a. Penetrating A2AD with Naval Assets

A viable option is to employ sacrificial afloat staging barges to detonate and take out certain mines in an identified region to clear a forward direction towards the contested islands. This option would constitute loss of assets but would allow the rear naval assets to passage through the sea minefield in the shortest possible time. Once a safe passage is clear by the sacrificial barges, high value assets such as an AFSB, or JHSV could commence to assault forward to deliver the troops and supplies. However,

the extent of sacrificial necessity needs to be weighed carefully. If there are enough intelligence gathered about the sea mines or patrol route, blockade runners could be employed to bypass the sea mines and patrols and penetrate through the A2AD umbrella, into the littoral area of the AO.

b. Penetrating A2AD with Aerial Assets

With AAM forming the protective umbrella around the AO, conventional aircraft options cannot be utilized effectively for airdrops or airbase delivery of cargo. An alternate option would be the employment of Joint Precision Airdrop Systems (JPADS), that utilizes GPS coordinates, steerable parachutes, and onboard computers to steer the cargo loads to the designated locations where ground troops could pick up the supplies. JPADS allows the cargo to be drop from 25,000 feet and still maintain a dropping accuracy of 75 meters 50 percent of the time. Essentially, this increases the standoff range of the aircrew from the adversaries AAM and increases their survivability. With the use of GPS, it reduces the risk of cargo missing a designated drop zone.

4. System Defends Against Attack: COI 4

The concept of defending can be decomposed into defending against surface threats, and defending against aerial threats. At this stage, it is assumed that Blue force had taken over the contested island and is prepared to mount a defensive stance against any plausible incursion of the Red force. The basic advantage that the Blue force requires is early warning, which could be achieved via persistent surveillance. Therefore, the in-theatre automated detection and tracking system must be robust to operate 24/7 round-the-clock, with minimal or no downtime. Here, the United States Northrop Grumman RQ-4 Global Hawk is a valuable asset that boasts long loiter times over target areas and possesses the capability of long range surveillance (over 40,000 square miles of terrain per day). Ground sensors could be employed on possible land areas for point area surveillance around the nearby coastlines.

a. Against Surface Threats

Viable measures to mount a credible defense against surface threats include employing Anti-Ship missiles, or mounting a naval barricade along the coastal lines towards probable direction of Red force ingress. In the event of Red force submarines, anti-submarines missiles are also warranted in the Blue force arsenal of weaponry.

b. Against Aerial Threats

The most basic defense options against incoming air threats are either the employment of Ground Based Air Defenses, or (Man Portable Air Defense Systems) (MANPADs). MANPADS are better suited to the least accessible waypoints on the island. Combat Air Patrols are the most straightforward defense measures, and they could be employed against both aerial and surface threats.

5. System Communicates: COI 5

a. Sub-Critical Issues

To establish and sustain communications, there are 2 COIs to be addressed:

(1) Interception:

There is a need to maintain operational security by denying adversaries of any opportunities to gain knowledge of operations on the AO. The adversary may place intercept receivers in the vicinity of the AOR (at the boundary of 12 NM of the island).

(2) Jamming:

There is a need to ensure communication channels are not denied by the adversaries. The adversary may use omnidirectional wideband jammers in the vicinity of the AOR under the pretext of conducting military exercises.

b. Operational Context

In addition, it is recognized that communications can be applied in two contexts:

(1) Communications within the AO:

This refers to all means of communication employed within the AO for command and control purposes by the relevant local authority.

(2) Communications outside of the AO:

This refers to all means of communications, which allows command and control purpose by the relevant remote authority.

c. Analysis

Currently, there are many established means of communications, which can be used as redundancies for each other. In this section, a qualitative analysis of the available means of communications was carried out based on the criteria of interception and jamming.

In addition to conventional wireless military communications (e.g. Ultra-high and very-high frequency radios), possible communications alternatives are listed in Table 18.

Table 18. Possible Communications Alternatives

Description	Context (internal external of AO)	Effective Against	
		Jamming	Interception
User Procedures and Techniques (e.g., minimal transmission, voice protocols)	internal/external		X
Lay Land Lines	internal	X	X
Low Altitude Balloon with LOS based Communications	external	X	X
Firing signal flares to elevated heights	external	X	
Periodic messenger trips via air delivery (e.g. UAVs)	external	X	X
Underwater Cables to friendly territory	external	X	X

H. USA/USAF TRADEOFF ANALYSIS

1. Delivery versus Attrition

The tradeoff analysis is based on delivery of initial troops and materials in a mined environment in which the island is incapable of supporting a vertical insertion due to insufficient size or lack of dry land. One alternative to aid insertion in such a scenario is to create a staging base on the other side of the minefield by sailing unmanned barges through the minefield and connecting them to each other once there. This alternative could prove acceptable if the gains won in establishing offset the material losses of barges due to mine attrition. Figure 18 depicts the expected losses in a scenario that requires 10 barges to successfully transit a 12.5 km wide minefield containing 20 mines with a .5 km damage radius. In this scenario, any barge that transited within the damage radius was deemed to not be capable of being used as part of the staging base. This scenario was run 10,000 time (100 simulation runs of 100 iterations each).

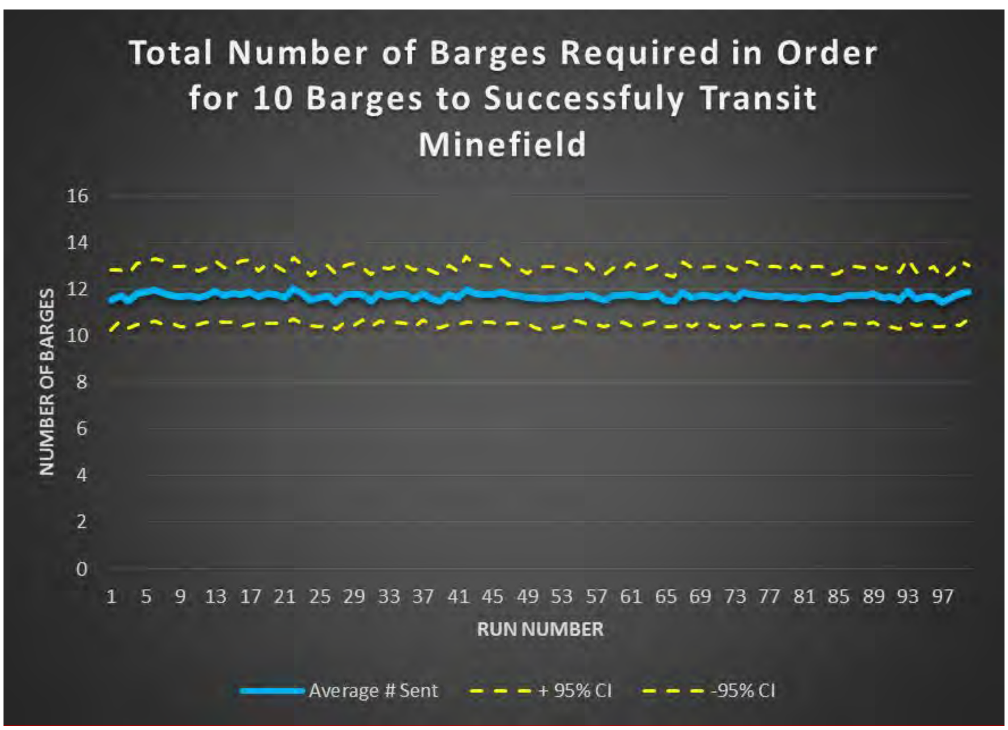


Figure 35. Barge Casualties

The results of the simulation show that on average no more than 4 barges will be attrited by mines. This indicates that 14 barges need to be sent into the field to have the desired 10 successfully make it through the field. An in depth discussion of this model is included in Chapter 11.

2. Use of Smart Sensor Field to Detect Enemy Intrusion

The probability of successful delivery operations depends on the capability of the transport aircraft to maneuver past the myriad of sensors to perform their intended delivery drops. Once the OPAREA is established successfully with the delivery of critical supplies, then the defensive operational requirements will be critical. On alternative to augment organic defensive capabilities is to deploy a smart sensor network in order to detect intruders. The nodes in such a network could be randomly distributed which would contributed to rapid placement but also incur a penalty in coverage efficiency. While randomly distributing the nodes would lower the impact the systems deployment would have manpower and time requirements, it will leave physical areas that have more or less than the number of sensors required to provide 100% coverage and detection. However, this may not be a significant issue if the sensors are used as a trip wire. That is, the primary purpose of the sensors would be to alert blue forces of enemy presence, as opposed to providing the precise location of every element of the intruding force.

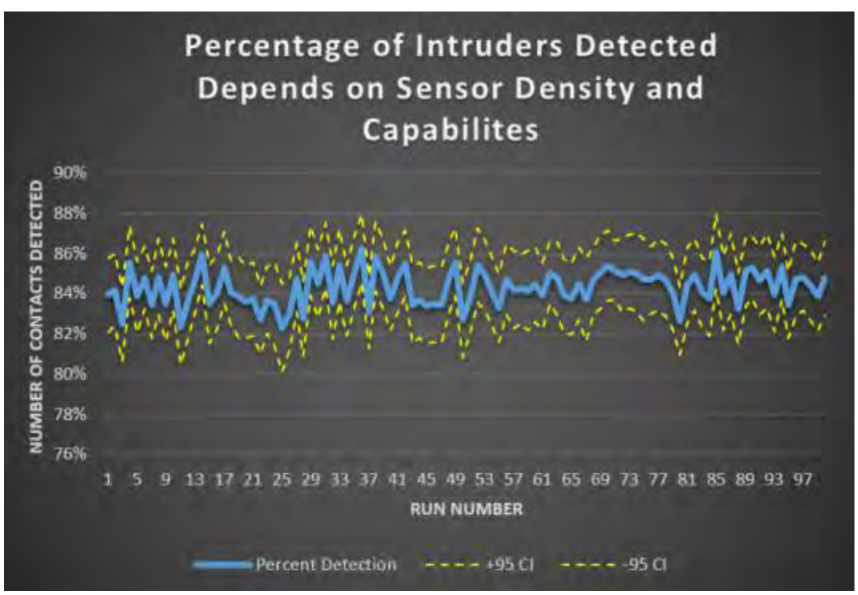


Figure 36. Intruder Detection by Networked Distributed Sensor Field

Figure 37 illustrates that preliminary analysis of 50 sensors randomly distributed around an island with a radius of 2 km. Each sensor has a detection range of .2 km and the model makes the assumption that there is a 100% probability that a sensor will detect an intruder in its detection range. This scenario was run 10,000 times (100 simulation runs of 100 iterations each). Results show that a field with the given parameters is capable of detecting 85% of the intruders. An in depth discussion of this model is included in chapter 11.

I. USA/USAF SYSTEM CONCLUSION

While there are many platforms and high-level technologies available for use for the USAF, the methodology of employing them at the right scenarios will have a great impact on the outcome of the operations. The design synthesis provided an overall broad view of the various functions required of the Army/Air Force component, while the operational analysis comes in the form of detailed COIs that are critical to the Army /Air Force component, namely delivery, sustenance and defense. The final tradeoff analysis provided an alternative perspective for the various COIs and outlines a separate functional analysis for the decision makers to make a more informed decision. In summary, the available platforms and technologies identified in this chapter allowed a multitude of operational options to be utilized by the Army / Air Force components to complete the required missions.

XI. MODELING AND SIMULATION

A. MODELING CONCEPTS FOR FEASIBILITY

Multiple models were created in order to provide data for quantitative analysis of the proposed courses of action. This section documents those models and presents preliminary analysis related to each model.

1. Distance

Deployable distances were determined by drawing circles with radii equal to platform operational ranges. Centering these circles on blue force deployment locations denoted the portion of the AOR a platform could reach. The assumption was made that platforms that were capable of refueling in transit would do so. Additionally, enough stores would exist on each platform to maintain the platform, crew, and transported troops during transit. The effectively infinite range imparted by these assumptions was tempered by the fact that project emphasizes speed of arrival at the target island.

2. Modeling First Arrival to Targeted Location

A stochastic model built using JavaScript, Cascading Style Sheets, and Hypertext Markup Language (HTML), was created to quantify each COA's ability to arrive at the targeted island first. This first arrival model allows the user to place multiple origination points for blue and Red forces on a graphic depicting the area of interest (AOI). Additional user inputs are:

- A user defined AOI to be evaluated
- Average speed of travel (along with a standard deviation) for the force stationed at each origination point
- Travel delay imposed on blue forces. This input is optional. Inputting a negative number indicates a head start for blue forces
- Number of sampling iterations. This number controls how many times each sample point is evaluated.

The AOI is created as a mesh of triangles with each of the triangle's vertices used as a sample point to determine first arrival. The number of triangles in the AOI mesh varies based on the size and shape of the AOI. For reference, the AOI shown in Figure 37

contains over 2600 triangles resulting in over 7000 sample points. The model measures the distance from each origination point to each sample point once per user defined iteration.

The distance between two points is calculated using these algorithm parameters:

- Get normalized three-dimensional coordinate of origin
- Get normalized three-dimensional coordinate of the sample point
- Normalized distance between the two points is the arccosine of the dot product of the normalized coordinate of the origin and the sample point
- This normalized distance is then divided by the user defined travel speed of that origin point
- It is not necessary to convert the normalized distance to real world distance because the model is only concerned with who gets to the point first
- As long as each force travels a consistently scaled distance the model will accurately determine who covers that distance fastest

Each point is sampled multiple times based on the number of iterations the user inputs. The color of the point is determined multiplicatively. For example, if the Red forces achieve first arrival to a point 60% of the time, while the blue forces arrive first 40% of the time, then the sample point color is set to 60% red and 40% blue. This results in a gradient of colors between the red and blue areas. This purple gradient represents the level uncertainty of which side will arrive first.

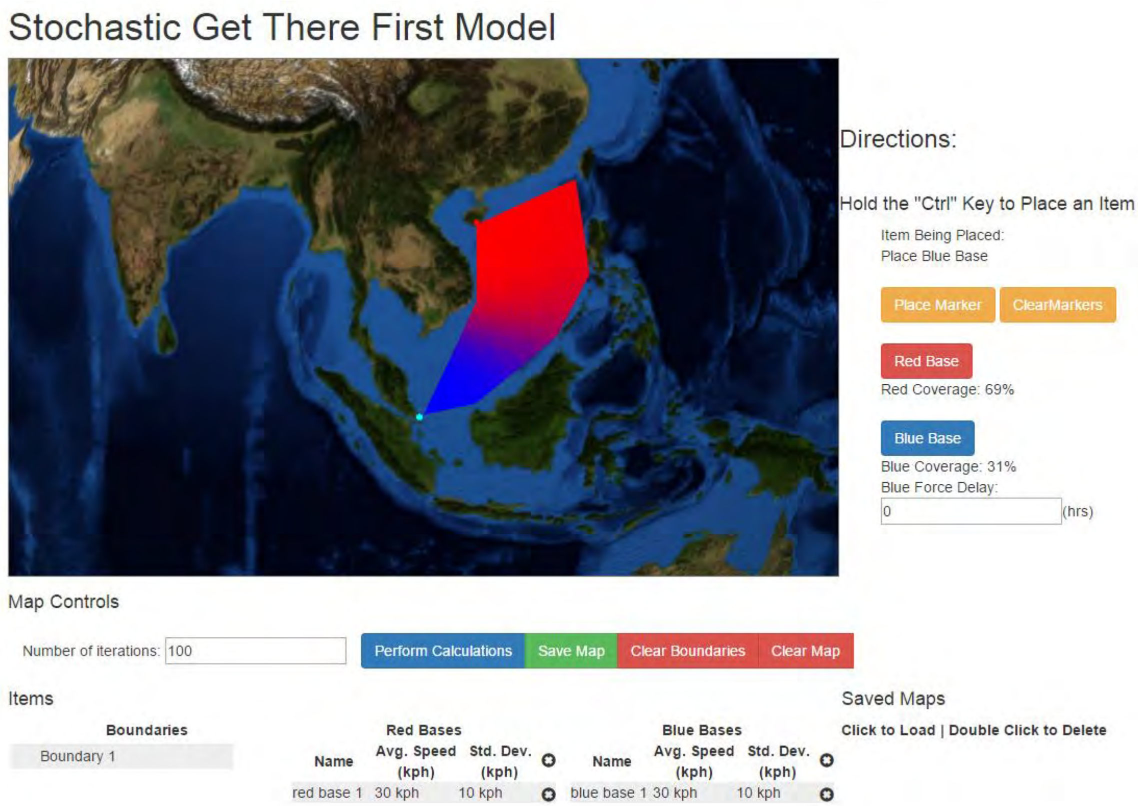


Figure 37. Stochastic "Get There First" Model Output

Preliminary analysis indicates that the ability to achieve first arrival on the target island varies based on four factors.

a. Red and Blue Force Travel Speed

The greater the speed advantage of the blue force, the better their chance to achieve first arrival.

b. Deployment and Destination Location

Each force's chance to achieve first arrival increases if they can deploy from a location close to the target.

c. Travel Range

This simulation assumes that both forces have infinite travel range. However, if ranges were to be limited in a subsequent modeling effort, and a target were placed outside of a force's range, then that force would be unable to achieve first arrival.

d. Delay Time

This represents the number of positive or negative hours between Red force deployment and Blue force deployment. In other words the delay can be a head start for either side in this problem. Every hour of exclusive movement the Red force has results in an expansion of their area of travel that cannot be recovered.

3. Initial Delivery and Sustainment Model

An agent based model was created using SIMIO, a modeling package that was originally designed for commercial applications (Kelton 2014). As an agent based model, it allows for the creation of individual units with specific physical characteristics including speed, cargo capacity, load, unload time, failure rate, and number of entities in model among other characteristics. This flexibility made SIMIO an obvious choice to use as the backbone of our logistics and supply system modeling. Additionally, agent based models allow for the exploration of a potential future system and encourage a more holistic thought process when building or creating a working model of a future system.

The modeled system represents the initial delivery and the logistics supply chain by sea or by air. The base model includes a small port, a large port, an airport, a helicopter delivery point and a supply arrival station. In between each of these locations are physical paths that mirror the distances required for ships to travel from Singapore to Natuna Besar. Each unit loads cargo at one of the ports and off loads the cargo at one of two destinations. The first represents the island and simulates the delivery of cargo directly to the beach. The second destination represents the need to off load cargo via helicopter or RHIB. The delivering unit remains at the offload site and the SH-60s and ribs deliver the cargo to the supply depot.

Each ship, airplane, or helicopter involved in the delivery of supplies to the force located on the island is represented in the model. Each unit has speeds and capacities that approximate reality. In most cases capacity was treated as universal in the sense that ten tons of food is the same as ten tons of fuel. The C-17 was added to the model to reflect the fact that there where physical limits to the Patriot Missile System that necessitated the inclusion of a larger aircraft that was capable of delivering the system.

Table 19. Unit Types Modeled Using Speed, Capacity, and Travel Distance

Unit Name	Capacity (tons)	Speed (kts)	Distance to Travel
Large Cargo Ship	1000	20	400
LCS	231	40	390
C-130	22	300	600
RHIB (LCS)	1	70	390
SSGN	1	10	400
JHSV	600	20	390
MV-22	10	250	600
LCAT	80	18	390
SH-60 (LCS)	4	20	20
C-17	80	400	600

The model using the data in Table 19 includes other elements as well. In this case, two sources were modeled: one represented physical cargo to be delivered and one represented the non-physical demand for resources by the personnel at the delivery location. The demand source generated units of cargo demand based on calculated requirements. Demand was modeled stochastically using a triangular distribution with inter-arrival times that ranged from 12 hours to 36 hours. This resulted in an average demand over a 24-hour period ranging from seven tons per day up to 20 tons per day.

Table 20. Experimental Configurations

	C-17	SSGN	JHSV	MV-22	LCS	LCAT	SH-60
COA-A (LCS)	0	0	1	0	3	0	3
COA-B (LCAT)	0	0	0	0	2	4	2
COA-C (MV-22)	0	0	1	5	0	2	0
COA-D (SSGN)	4	2	0	0	0	0	0
COA-E (C-17)	6	0	0	0	0	0	0

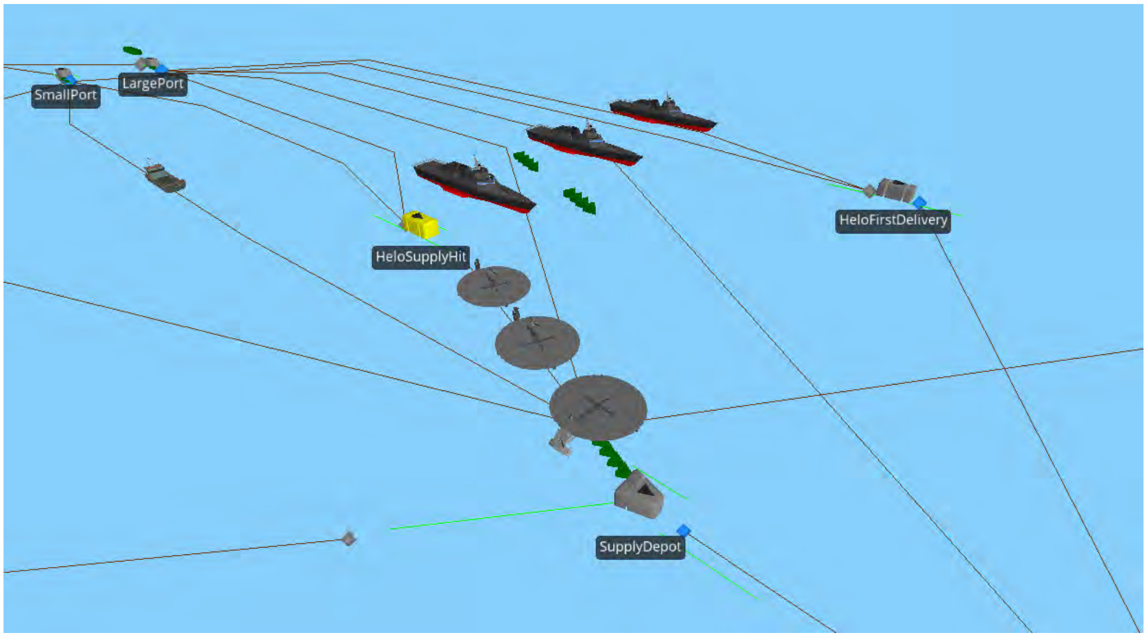


Figure 38. SIMIO Model Showing SH-60s Shuttling Cargo from LCS

Each COA was modeled to represent the number of platforms used to execute each plan. Additional experiments were conducted to verify that each COA option was able to provide sufficient quantities of supplies for sustainment. For example, if a COA used all aircraft then the model was tested to verify that one single aircraft would be able to provide enough supplies for sustainment. Likewise, if a COA used LCS, then an experiment was conducted to verify the suitability of one LCS to deliver timely resupply.

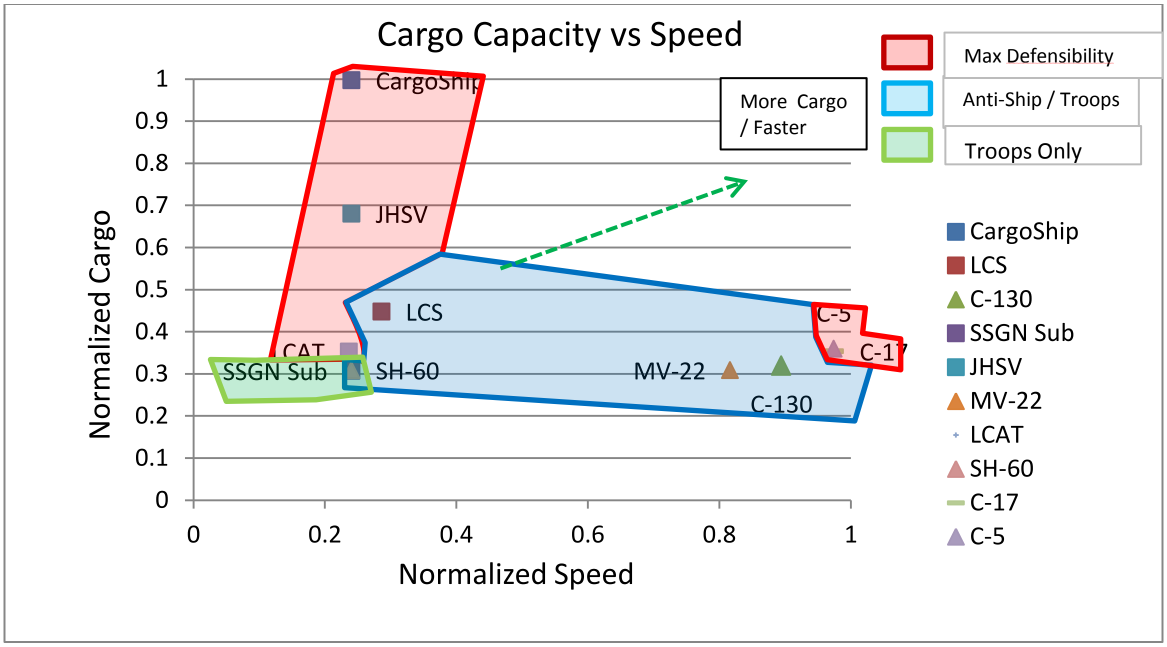


Figure 39. Cargo Capacity versus Speed with Defendability Overlay

Figure 39 illustrates the relationship of a range of platforms with respect to speed and cargo capacity. The upper right corner is where the fastest platform with the highest cargo capacity would reside. The chart includes a color coding that highlights three levels of defendability: anti-ground, anti-surface, and anti-air. Platforms that are only able to deliver ground troops are coded green. All platforms that can deliver troops and surface to surface defensive missile systems are coded in blue and those capable of carrying the largest anti-air missile system we considered, the Patriot, are coded in red. Unsurprisingly, the larger ships and naval vessels are able to deliver the Patriot missile system and the smaller ship, the LCS, and aircraft are only able to deliver the anti-ship missile systems. The smaller platforms and aircraft, while faster, carry significantly less cargo when compared to ships. Of note, the Air Force transports C-17 and C-5 break away from the cluster of slower naval vessels and aircraft. They are by far the fastest platform suitable for delivering the Patriot system and thus bring maximum defendability in the shortest time.

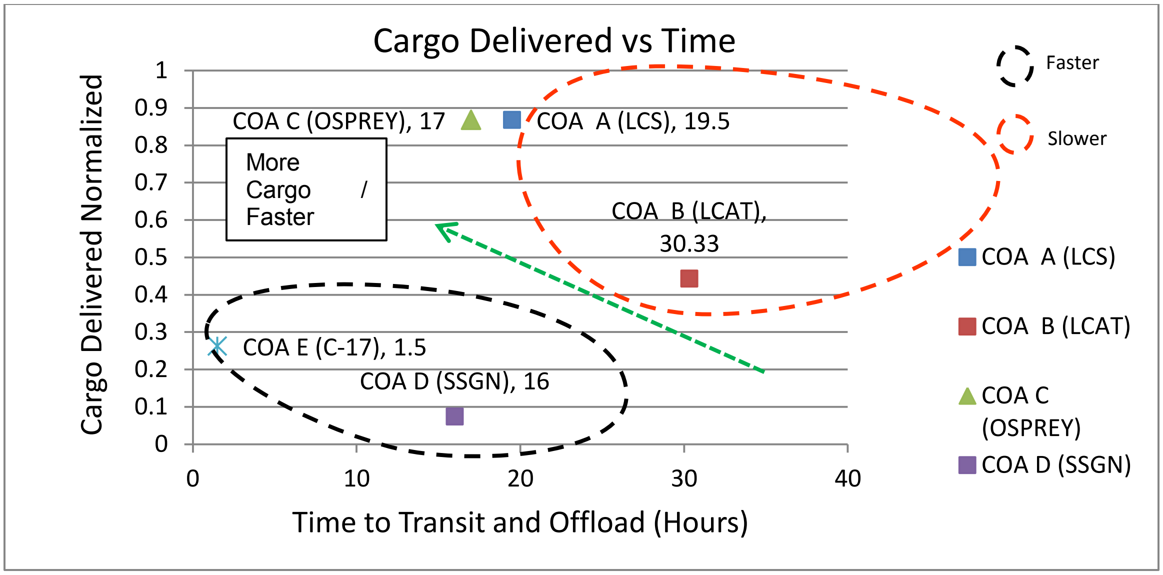


Figure 40. Cargo Delivered versus Time

Figure 40 shows the actual time of delivery for each COA in relation to the amount of cargo delivered. The delivery time is based on the amount of time it took to deliver all of the cargo required. Each COA that uses the Landing Catamaran (LCAT) was inhibited by its maximum speed while loaded of 18 knots ("LCAT" 2014). In this case, it had an effect on the time to deliver in COA B and C. The limiting factor for COA A was the time to offload the LCS vessels using both helicopters and the rib boats. With one rib and one SH-60 per LCS, the total time to deliver the initial load of troops was 19 1/2 hours. COA C was the median of the five COAs at 17 hours. The unique benefit of COA C was that it would be able to reduce the time required by simply moving closer to land.

Table 21. Results for Delivery Times

Experiment	Number of Simulations	Mean Time to Deliver (hours)	Distance to Travel (NM)
COA A	30	19.5	390
COA B	30	30.3	390
COA C	30	17.7	600
COA D	30	16	390
COA E	30	1.5	600

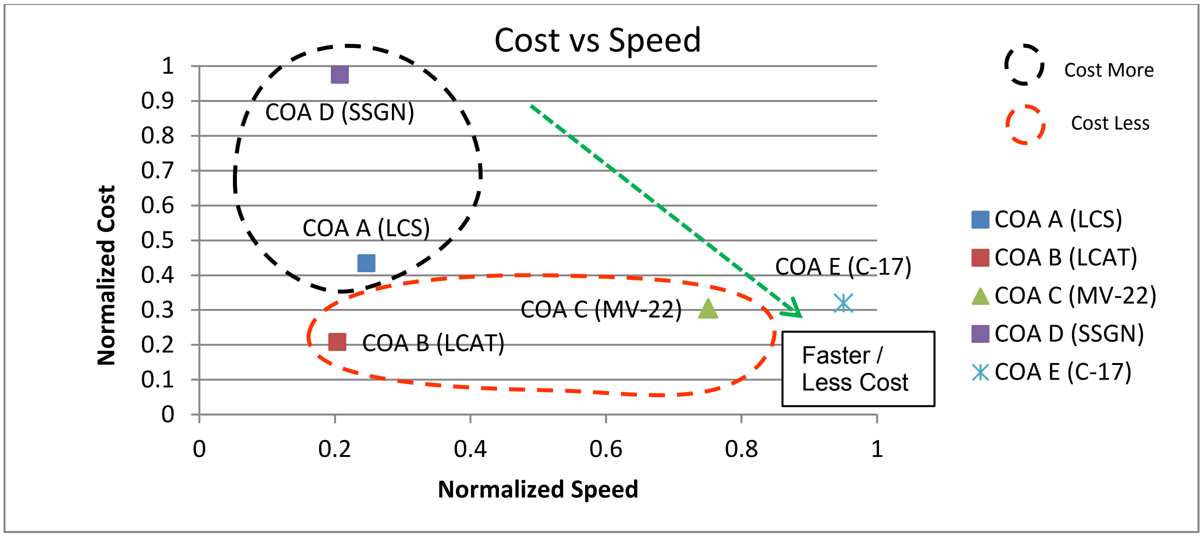


Figure 41. Normalized Cost versus Normalized Speed

Figure 41 shows the relationship of cost and speed in the COAs. The fastest and the least expensive are in the lower right corner. In this case, the lowest cost option, COA B, is also one of the slowest. The fastest option, COA E, is the median cost and the next fastest, COA C, is even less expensive. Of the two with the lowest cost, one, COA C, is significantly faster.

4. Resupply Modeling

Each COA was designed to be able to provide resupply using only the platforms available within that COA. The range of supplies required was calculated to be from seven tons per day to 20 tons per day based on workload. For example, a single C-130 would be able to provide 20 tons per sortie. This tonnage equates to a range from 1 to 2.8 days before more supplies are required. Simple math in this case was enough to establish a minimum requirement and show that each COA would over deliver if all of the platforms were used for resupply.

A commander in an operational setting would have a full range of platforms available, including civilian contractors. Figure 42 shows the full range of options available and how long the supplies would last for the troops located on the island.

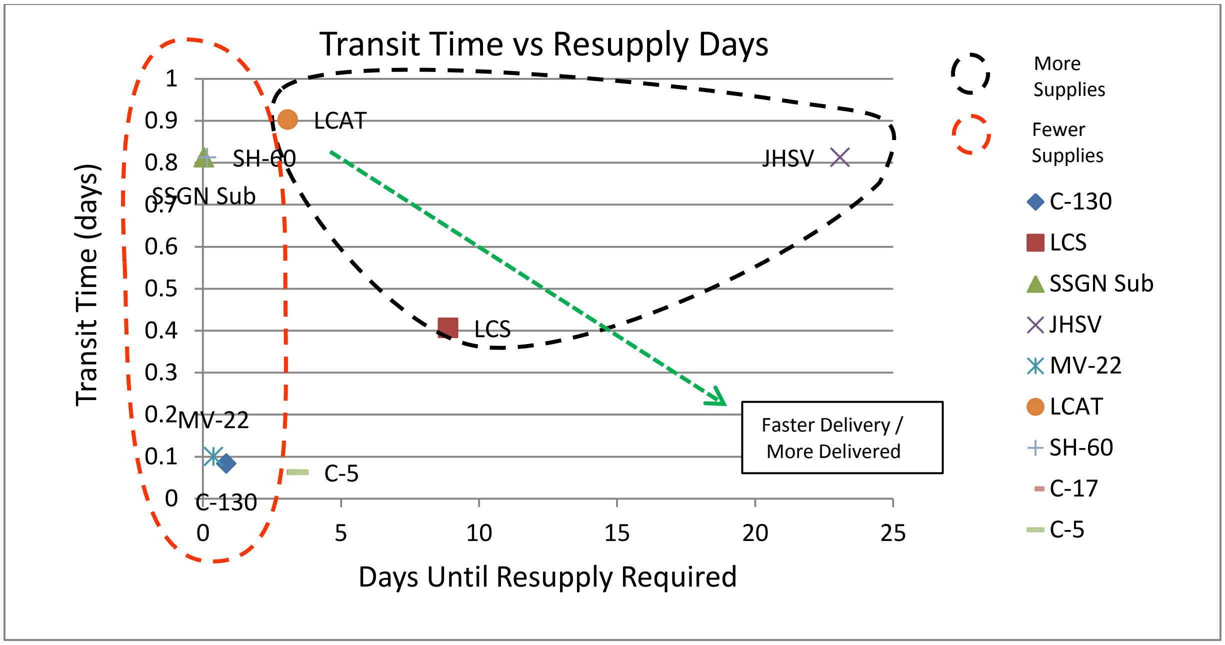


Figure 42. Transit Time versus Resupply Days

The three top performers were the LCAT, the LCS, and the JHSV. All three of these platforms would be able to transit in less than 24 hours and would provide 4, 8, and 23 days of supplies respectively. Under average demand, 13 tons per day, supplies would last for 6, 17, and 46 days.

5. Force Package Defendability Modeling

A Microsoft Excel model using the Hughes' salvo equations was created in order to determine organic defensive requirements for the landing force to provide a level of defense great enough to deter an enemy attack (Hughes 2000). The Hughes salvo equations model is a wide used model for modeling missiles combat. We used it because of the major importance of the missile battles for attacking/defending the island, in contrast to the land battle. Both of the battles types in our scenarios, the surface-to-surface battle and the surface-to-air battle could be modeled as rounds of missile or bombs attack. The model evaluates the remaining force after each round, until one of the forces is eliminated.

The main question we tried to answer using the model is "How much missile systems (Patriot and NSM) the Marines should deploy in the island in order to create a credible threat?" we were interested more in rough estimations than exact number because we modeled a deterrence force. We assumed that the Red Side will do a similar calculations, which should lead them to the conclusion that a battle for the island will be hard, if the Marines will pose a credible threat. Two scenarios were analyzed to determine these requirements. The first scenario was a battle between surface-to-surface missiles pitting the NSM and Patriot systems against the Chinese Type 022, equipped with Hongniao missiles. The second scenario was a surface-to-air engagement of Patriot batteries against Chinese J-15 tactical aircraft.

Each scenario was examined at medium and high threat levels using Spratly and Natuna Besar-sized islands as references. Nine user inputs were used in formulating strengths of both the Red and Blue sides of the engagement, and are listed here:

1. Number of Weapons systems
2. Targeting ability
3. Missiles per Salvo
4. Probability of hit
5. Hit absorption
6. Defensive firepower
7. Defensive readiness at first round
8. Defensive alert after 1st round
9. Scouting effectiveness

a. Scenario 1: NSM and Patriot Versus Type 022 Vessels

(1) Medium threat – Natuna Besar

Several assumptions were required when setting up the three aspects of this scenario. These are the assumptions for the first part of this scenario:

- Chinese forces will shoot first, and U.S. forces operate under defensive rules of engagement
- The NSM is maneuvering, so the Type 022 probability of hit is low
- We assume firing in range, although **Hongniao range** is much larger than NSM ("Weapons" 2013) ("Strike" 2015")
- As a missile, the NSM has a low ability to absorb hits and remain effective
- The Type 022 missile boat has no anti-missile capabilities.
- Each Patriot battery has four missiles each with an estimated 0.95 probability of kill against the Hongniao missiles

- The Chinese has advantage in scouting because the island is a stationary target. Conversely, their Type 022 vessels have the ability to attack from almost any direction
- We assume that the Chinese will have 7 to 9 Type 022 vessels at the medium threat level and 11 to 13 at the high threat level
- We assume from the air-battle results that Blue forces in Natuna Besar will have two Patriot batteries in a medium threat environment

Table 22. Input Values: Surface threat—Medium Threat—Natuna Besar

	U.S.		CHINA	
NUMBER OF VESSELS	1	NSM	7	Type 022 (Hongniao)
TARGETING ABILITY (COEFF.)	0.8		0.3	
MISSILES / SALVO	4		8	
PH	0.8		0.4	
HIT ABSORPTION	1		2	
DEFENSIVE FIREPOWER/SHIP	11.4		0	
DEFENSIVE READINESS	1		1	
SCOUTING EFFECTIVENESS	0.9		1	

This resulted in the Chinese forces being able to defeat U.S. forces on the island if they attack with at least eight Type 022 vessels.

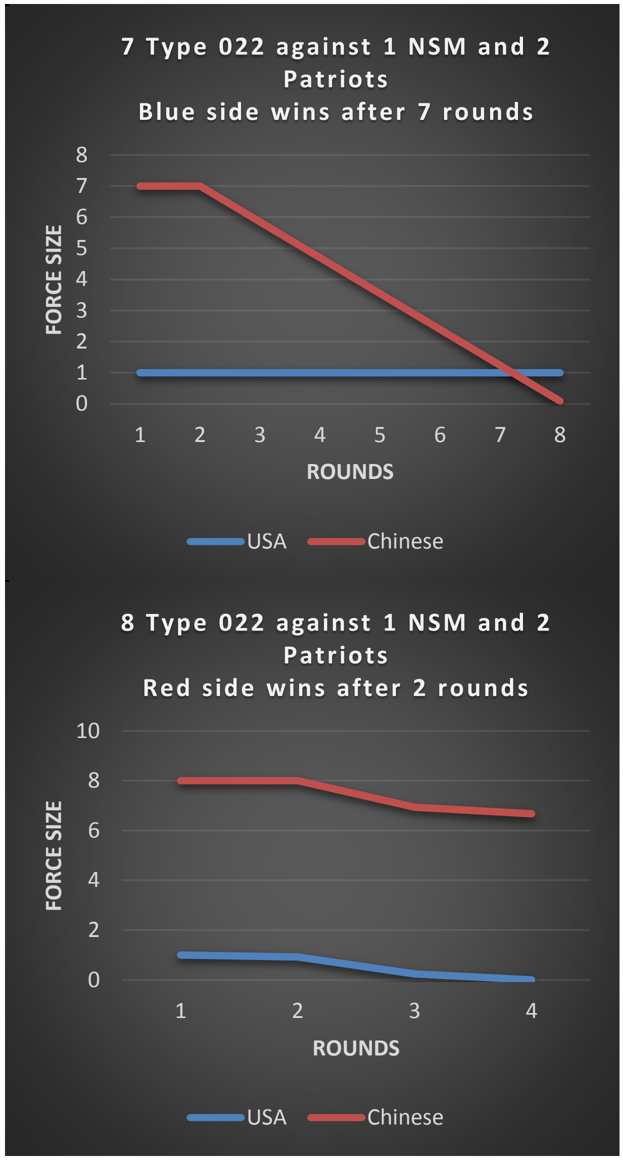


Figure 43. Salvo-Equations Results: Surface threat—Medium threat—Natuna Besar

The air defense capabilities of the Patriot missiles play a very important role in this scenario. There should be very little surprise that the NSM is relatively less effective in a situation where there are less than 12 Type 022 vessels because in such cases Patriot batteries are able to engage all incoming enemy missiles. The non-linear results shown in Figure 43 are due to mathematical properties inherent to the Hughes-Salvo deterministic model. These results should be considered with extra care, as deterministic estimates are not subject to a probabilistic range of outcomes.

(2) High Threat - Natuna Besar

These are the assumptions for the second part of this scenario:

- Chinese forces will shoot first, and that U.S. forces operate under defensive rules of engagement
- The NSM is maneuvering, so the Type 022 probability of hit is low
- We assume firing in range, although **Hongniao range** is much larger than NSM (“Weapons” 2013) (“Strike” 2015)
- As a missile, the NSM has a low ability to absorb hits and remain effective.
- The Type 022 missile boat has no anti-missile capabilities
- Each Patriot battery has four missiles each with an estimated 0.95 probability of kill against the Hongniao missiles
- The Chinese has advantage in scouting because the island is a stationary target. Conversely, their Type 022 have the ability to attack from almost any direction
- We are assuming from the air-battle results that Natuna Besar will have 3 Patriot batteries in the high threat scenario

Table 23. Input values: Surface Threat – High Threat – Natuna Besar

	U.S.		CHINA	
NUMBER OF VESSELS	1	NSM	11	Type 022 (Hongniao)
TARGETING ABILITY (COEFF.)	0.8		0.3	
MISSILES / SALVO	4		8	
PH	0.8		0.4	
HIT ABSORPTION	1		2	
DEFENSIVE FIREPOWER/SHIP	11.4		0	
DEFENSIVE READINESS	1		1	
SCOUTING EFFECTIVENESS	0.9		1	

This model resulted in the Chinese forces needing at least 12 Type 022 vessels to achieve a victory.

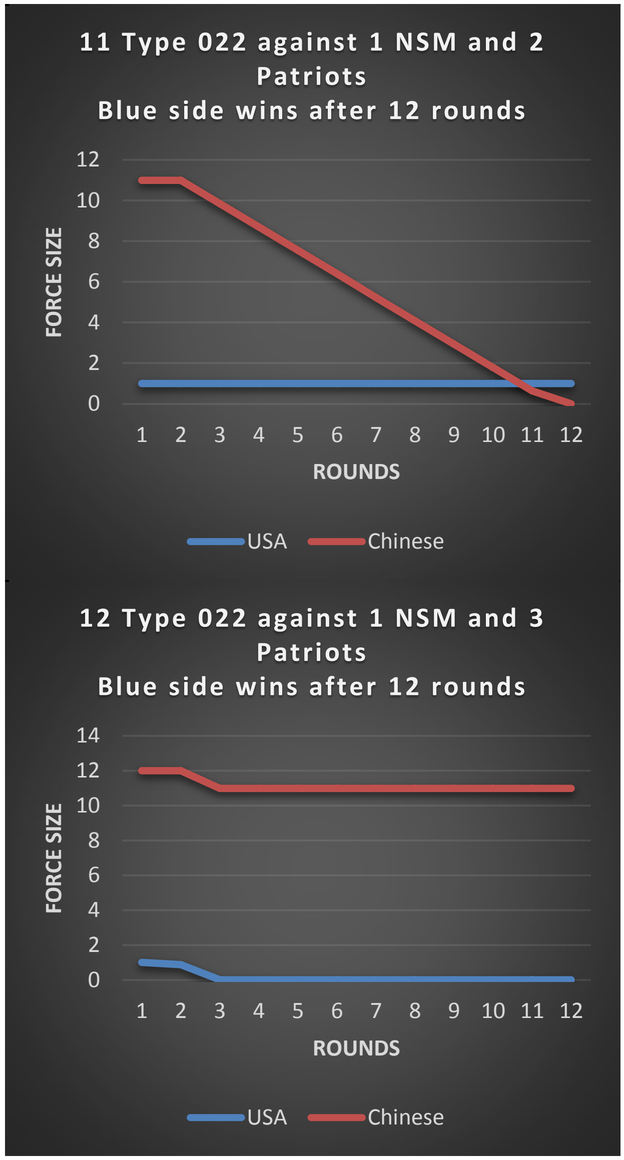


Figure 44. Salvo-Equations Results: Surface threat—High threat—Natuna Besar

(3) Medium and high threat—Spratly Islands

These are the assumptions for the third part of this scenario:

- Chinese forces will shoot first, and that U.S. forces operate under defensive rules of engagement
- The NSM is maneuvering, so the Type 022 probability of hit is low
- We assume firing in range, although the Hongniao range is much larger than NSM (“Weapons” 2013) (“Strike” 2015”)
- As a missile, the NSM has a low ability to absorb hits and remain effective

- The Type 022 missile boat has no anti-missile capabilities
- Each patriot battery has four missiles with an estimated 0.95 probability of kill against the Hongniao missiles
- The Chinese has advantage in scouting, because they know where to aim (the island) and the attack could come almost from everywhere.
- It will not be possible to land more than 1 NSM and 1 Patriot in the Spratly Islands because of its size
- The Chinese will not attack the island with a full force because of its size. We assume 4–5 Type 022 for a medium threat scenario, and 7–9 for a high threat scenario

Table 24. Input values: Surface threat—Medium and High threat—Spratly Islands

	U.S.		CHINA	
NUMBER OF VESSELS	1	NSM	4	Type 022 (Hongniao)
TARGETING ABILITY (COEFF.)	0.8		0.3	
MISSILES / SALVO	4		8	
PH	0.8		0.4	
HIT ABSORPTION	1		2	
DEFENSIVE FIREPOWER/SHIP	3.8		0	
DEFENSIVE READINESS	1		1	
SCOUTING EFFECTIVENESS	0.9		1	

The results of this scenario revealed that U.S. forces should expect to win the engagement if there are four or fewer Type 022 missile boats.

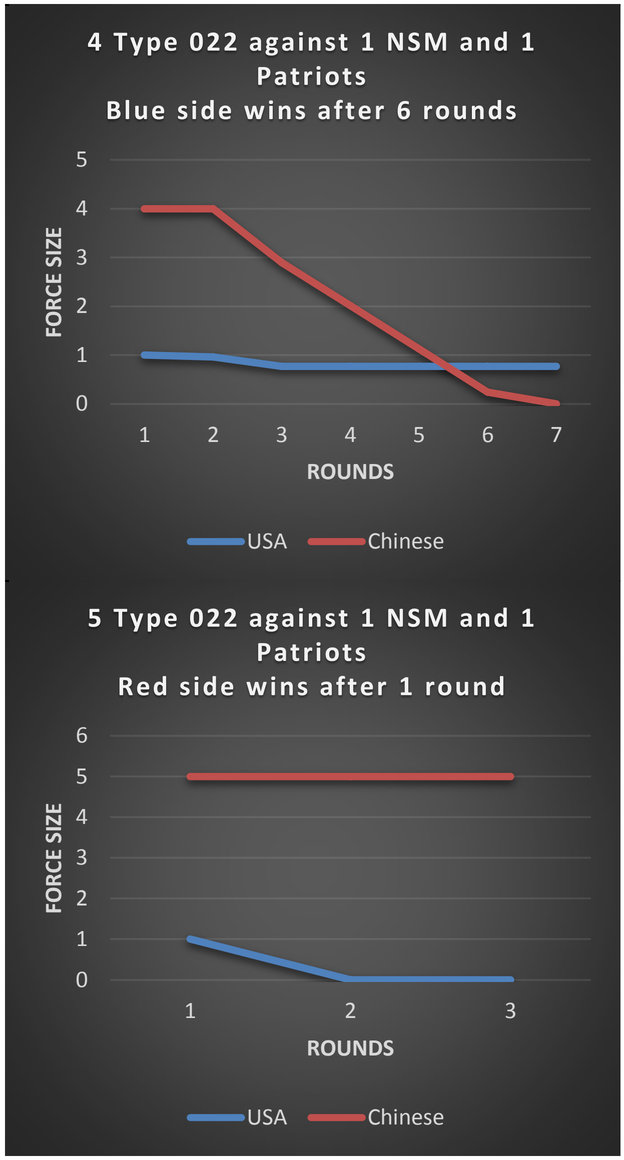


Figure 45. Salvo-Equations Results: Surface threat—Medium and High threat—Spratly Islands

(4) Conclusion

The Spratly Islands configuration is capable of mounting a successful defense using systems organic to the force protection package. However, no package in the Spratly Islands is deemed sufficient for defense against a high-level threat.

(5) Sensitivity Analysis

As before, the model is very sensitive to the performance of the Patriot missiles. This is because the Patriots create an effective anti-air shield enabling the NSM to attack the Type 022 vessels unmolested.

For example, Figure 46 is a plot showing the maximum number of Type 022 vessels that a Blue side configuration is capable of defeating. The plot is varied by the number of Patriots batteries and the number of NSM batteries.

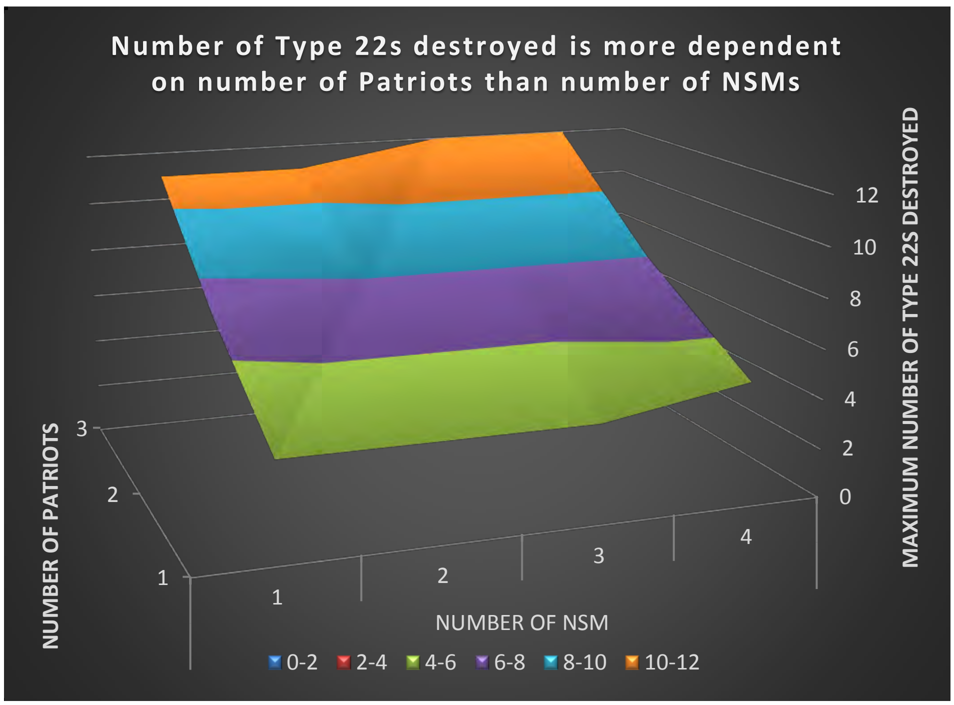


Figure 46. Sensitive Analysis of Number of Patriots and Number of NSMs in the Salvo-Equations Model

From Figure 46, it is clear that changing the number of Patriot batteries increases the number of Type 022 vessels that can be defeated by three or four ships, while the improvement in threats defeated by the NSM over the same range is less than one. This reveals a much greater sensitivity for the Patriot system. In fact, 66% of time the NSM increase resulted in no increase in the number of Type 022s defeated.

b. *Scenario 2: Patriot versus J-15 Aircraft*

(1) Medium and High Threat – Natuna Besar

The assumptions for this scenario are:

- The LS PGB guided bomb is the primary anti-surface weapon of the J-15. (“Laser” 2012) It has a range of approximately 27 NM (50 km), which is much shorter than the PAC-2 range of 52 NM (96 km) (“Patriot” n.d.). The Patriot’s range advantage gives it first strike capability.
- The Patriot missile speed (Mach 4.1) (“Patriot” n.d.) is twice the speed of the J-15 (Mach 2.4) (“Shark” 2011), resulting in the Patriot having a high probability to hit and kill assuming correct guidance.
- The J-15 has an effective electronic warfare payload providing an anti-missile capability (Weening, 2014). We assume this capability allows the J-15 to shoot down two Patriot missiles each time.
- Both the Patriot and the J-15 have low ability to survive being hit.
- A medium threat attack consists of two J-15s. A high level attack consists of four J-15s.

Table 25. Input Values: Air Threat—Medium and High Threat—Natuna Besar

	U.S.		CHINA	
NUMBER OF VESSELS	2	Patriot	1	J-15
TARGETING ABILITY (COEFF.)	0.95		0.95	
MISSILES / SALVO	4		2	
PH	0.9		0.8	
HIT ABSORPTION	1		1	
DEFENSIVE FIREPOWER/SHIP	0		2	
DEFENSIVE READINESS AT FIRST ROUND	0.9		1	
DEFENSIVE ALERT AFTER 1ST ROUND	1		1	
SCOUTING EFFECTIVENESS	1		1	

The results of Table 25 inputs reveal that U.S. forces can win a in a medium threat environment with two Patriot batteries, while three batteries are required to succeed when the threat level is high.

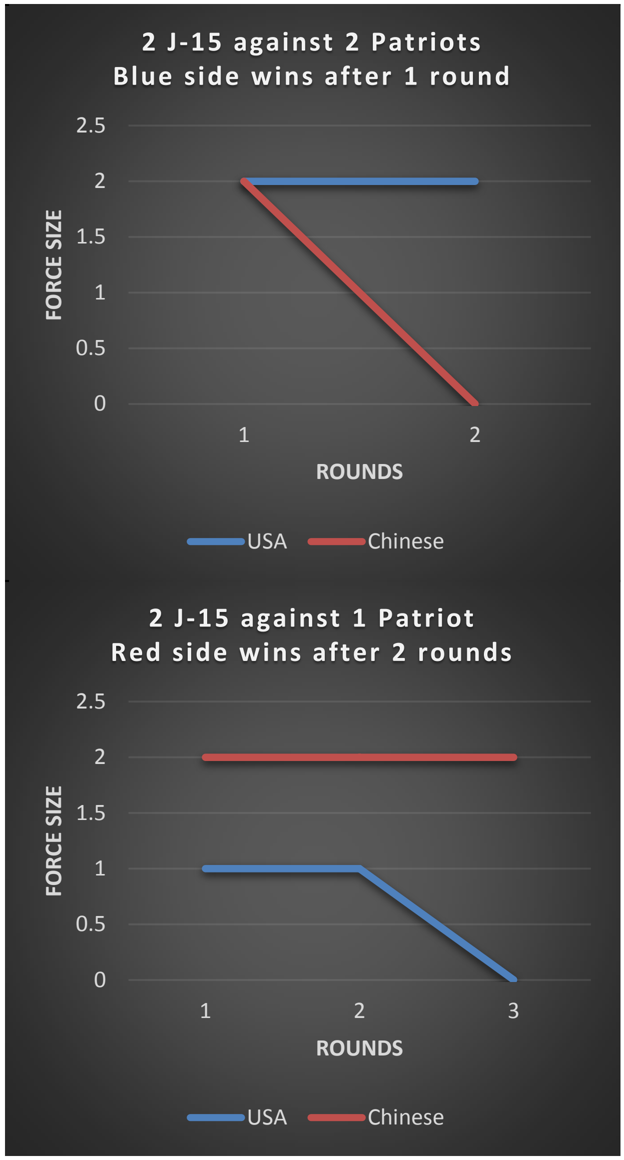
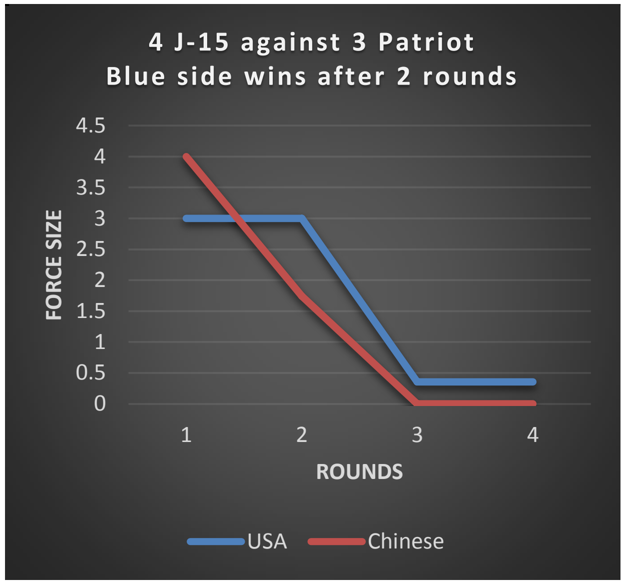


Figure 47. Salvo-Equations Results: Air Threat—Medium Threat—Natuna Besar



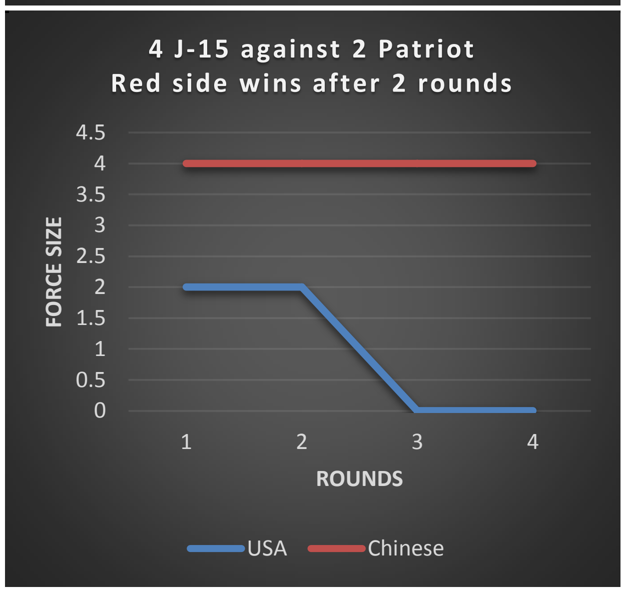


Figure 48. Salvo-Equations Results: Air Threat—High Threat—Natuna Besar

This type of threat can only be handled in a Natuna Besar type scenario; the island used in the Spratly Island scenario is too small to support more than one Blue asset of any type (NSM or Patriot). With only one defense system, Blue forces lose all air-battles when only organic defense systems are used.

6. Surveillance Unmanned Arial Vehicle (UAV) Modeling

Map-Aware Non-uniform Automata (MANA) is an agent based simulator that allows for very detailed modeling of various military platforms (Lauren 2002). MANA can be programed to allow for units to search, asses line of sight, and attack enemies with or without coordination with other friendly units. Single run or multiple run simulations can be performed using various stochastic starting points to assess robustness of design.

One of the goals for the COAs was for each of the deployment packages to have an indigenous ISR capability that would allow the occupants to monitor the sea and air space surrounding the island for intruders. One possibility was for the use of small low cost UAVs, but the number of UAVs that would be required to provide adequate surveillance was unknown.

The UAVs were given basic characteristics of a small quadcopter and assigned the task of patrolling around the island. Figure 52 shows the enemy forces, composed of 15 boats (red dots), staged in a posture surrounding friendly territory, which were programmed to move toward the island, as shown in Figure 53. A group of quadcopters (blue dots) with sensor ranges of 3,400 yards (3 kilometers) with a sweep width of 320^0, forward, at an altitude of 1,000 feet traveled at 27 knots through the patrol area. When the quadcopters randomly patrolled the entire area out to a 12 nautical mile radius from the island, they were unable to ensure that none of the enemy vessels made it to the island undetected. After 30 simulations, using four UAVs searching randomly, 60% of the simulations resulted in at least one enemy vessel getting to the island undetected.

Given this result, a modified search was tested. The number of quadcopters was reduced to three and one was programed to remain hovering over the island. This simple change prevented any enemy vessel from closing to within 5,400 yards (5 kilometers) of the island. A separate four quadcopter model was tested and it also prevented the enemy from closing within 5,400 yards while the overall range at which the enemy was detected increased. It demonstrated that search patterns have a greater influence over performance then the sheer number of quadcopters used.

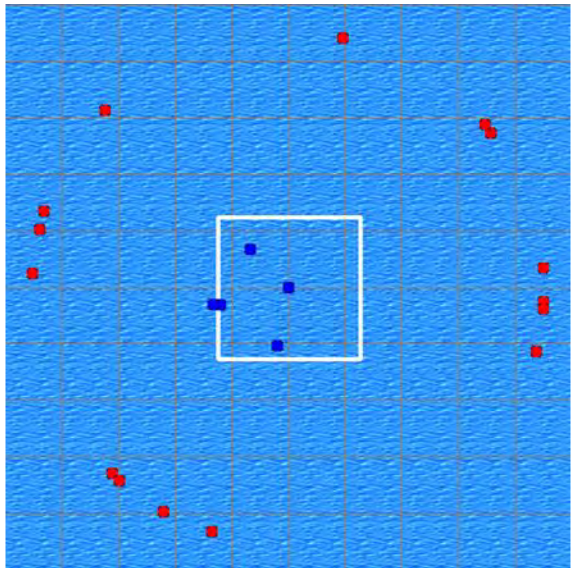


Figure 49. Mini-map View of Sea Area

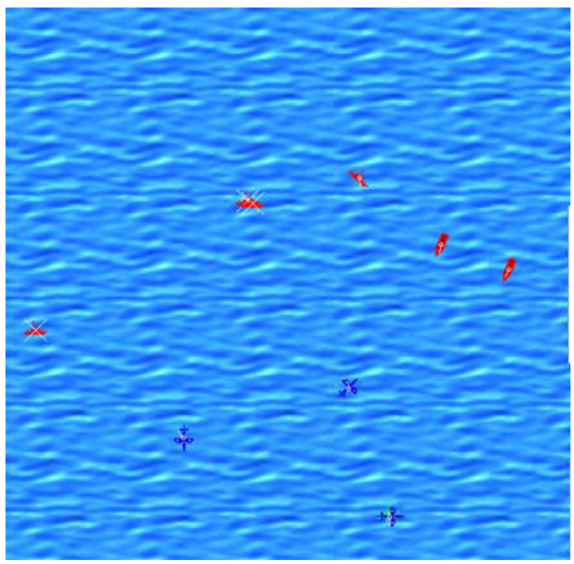


Figure 50. Map Showing Enemy Ships Moving Toward Island

7. Insertion Onto a Small Island in a Mined Environment

A Monte Carlo simulation based on Professor Alan R. Washburn's "Un-countered Minefield Planning Model" (Washburn, 8) was created to calculate platform attrition during a sea insertion to an island that was unable to support vertical insertion and inside of a mine field. Such a situation would preclude using air assets to deploy due to geography, and deploying manned surface assets due to risk of loss due to the mines.

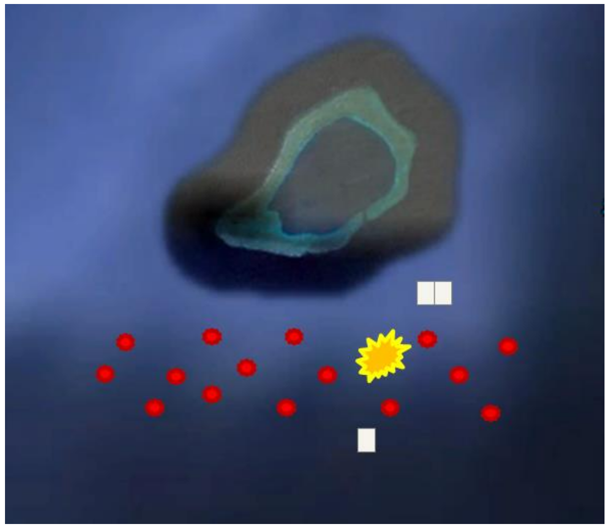


Figure 51. Simulation Snapshot of Multiple-Barge Minefield Transit

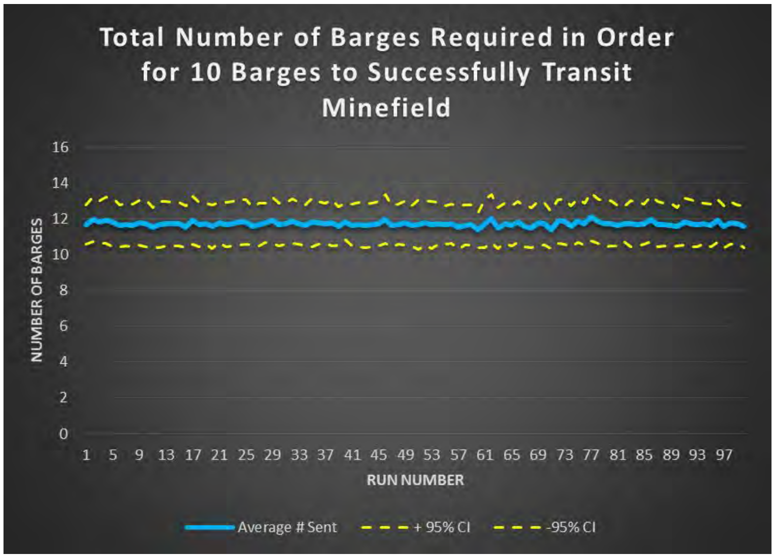
One solution would be to send relatively inexpensive unmanned barges through the field using the same path. Barge attrition due to a mine would also result in the attrition of that mine and removal of its ability to affect subsequent barges using the same path. Eventually, enough barges would make it through the field that they could connect and form the basis for a landing pad for follow on vertical lift efforts. Analysis would indicate expected barge loss given these user inputs:

- Number of mines in the field
- Damage radius of individual mines
- Width of the mine field
- Probability of activation for each mine
- Number of platforms required on the other side of the field
- Platform travel jitter

The mitigation effects of rapid mine clearance techniques could be included by altering the overall number of mines in the field.

This simulation works by uniformly distributing the given number of mines across the width of the field, which is simulated by the x-axis. Next, a random location is selected on the x-axis representing the path the barges will take through the field. If the selected x-value falls within the damage radius of a mine then both the mine and the barge are destroyed, otherwise the barge is considered to have made it through the field safely. Subsequent barges use approximately the same x-values (the amount of deviation

is based on the given jitter values); either activating remaining mines in the vicinity or safely passing through the minefield. The simulation stops after the desired number of barges make it through. An example output of this simulation is shown in Figure 52.



Example Parameters:

- 10 barges required
- 12.5 km wide minefield
- 20 mines
- Mines actuate upon detection
- 0.5 km kill radius per mine
- Mines randomly distributed across minefield
- 100 simulation iterations per run (total of 10,000 simulations)

Figure 52. Monte Carlo Simulation Output for Minefield Casualties

Preliminary analysis indicates that platform attrition is dependent on the mine density as well as the detection and damage radius of the mines. A field that is less densely filled with less sensitive and damaging mines has a lower attrition rate than one that is more densely filled with more dangerous mines.

The attrition results of a denser field with more mines in shown in Figure 53:

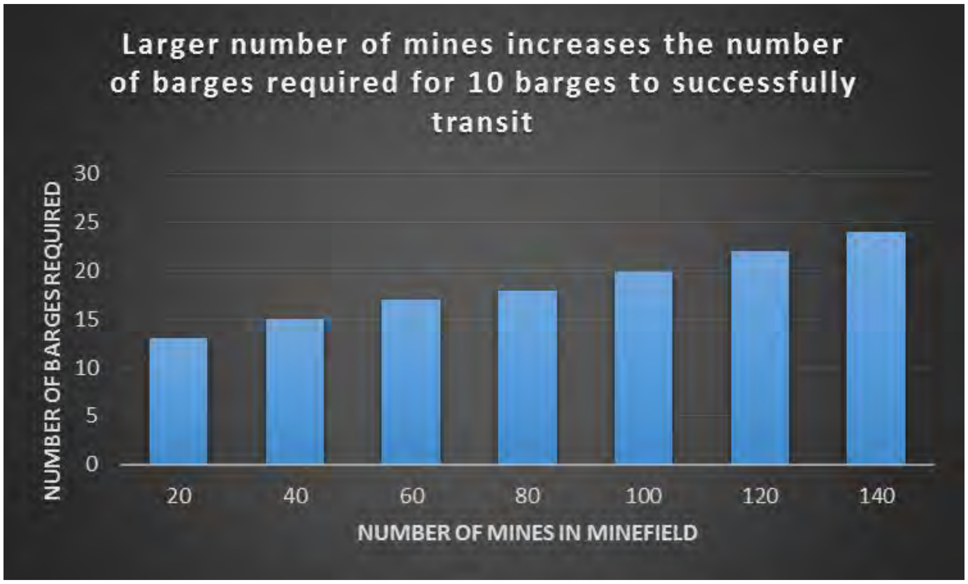


Figure 53. Barge Attrition as a Function of the Number of Mines

Figure 54 shows the effect that mine damage radius has on the number of barges required to achieve tasking.

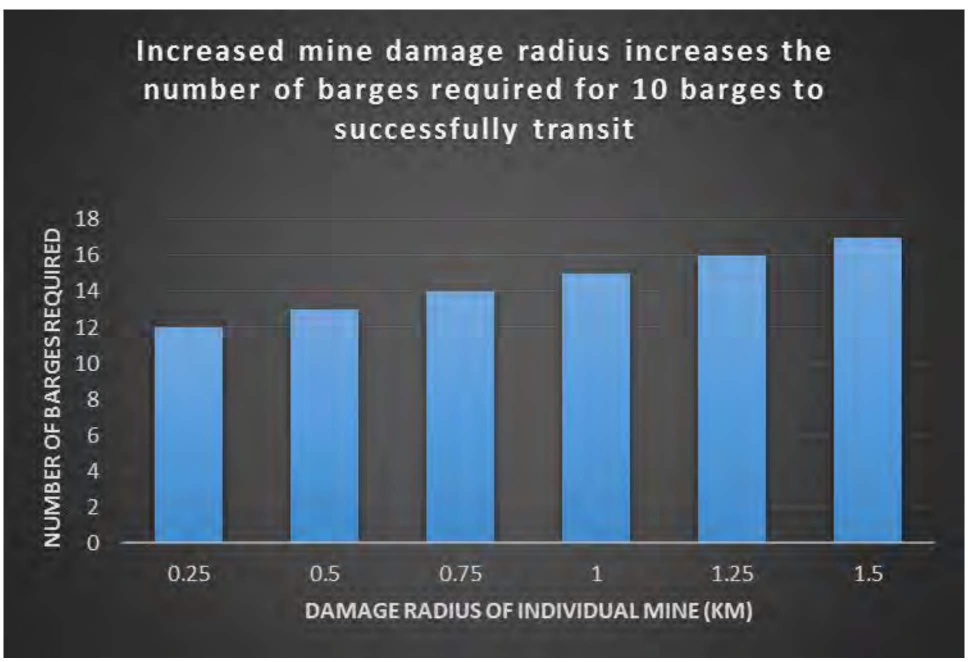


Figure 54. Barge Attrition as a Function of Individual Mine Damage Radius

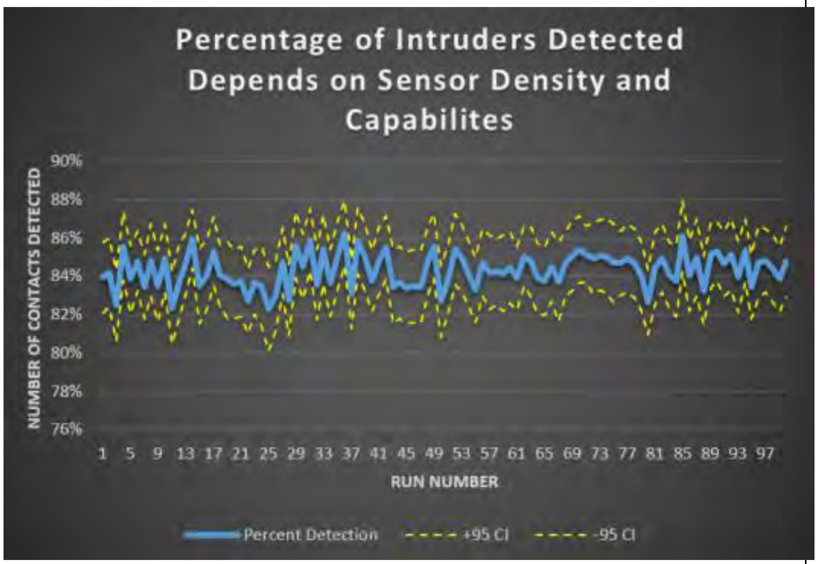
8. Smart Sensor Detection

The Smart Sensor Field Detection model is a Monte Carlo simulation created to quantify intruder detection through a sensor field consisting of a randomly distributed network of sensor nodes. The equipment simulated in this model is meant to alert the defending forces to the presence of the intruder. It is not beyond the realm of possibility that this concept could be expanded to include a sensor system with an engagement component; however, such a component lies beyond the scoped boundaries for this particular project.

User inputs in this model are:

- Number of sensors in the field
- Detection radius of individual sensors
- Width of the sensor field
- Probability of detection for each sensor

This model is also based on the aforementioned Washburn model mentioned in the Section 3 of this chapter. An example output is shown in Figure 52. The differences between the outputs shown in Figure 53 and Figure 54 come in the form of three exceptions for the latter simulation. The first is that any intruders enter the field at random locations. The second is that in this case sensors are not destroyed upon activation. The third is the intruders are also not destroyed upon detection by the sensors.



Example Parameters:

- 50 sensors
- 250 meter detection radius
- 90% probability of detection
- 12.5 km wide sensor field
- 100 simulation iterations per run (total of 10,000 simulations)
- 20 intruders

Figure 55. Monte Carlo Simulation Output for Smart Sensor Field Detection

Figure 55 shows that the percentage of the 20 intruders that are detected is influenced by the number of sensors in the system. In this simulation, only the number of sensors parameter is changed; all other parameters remain the same as Figure 52. It indicates that a denser sensor field is more effective at detection.

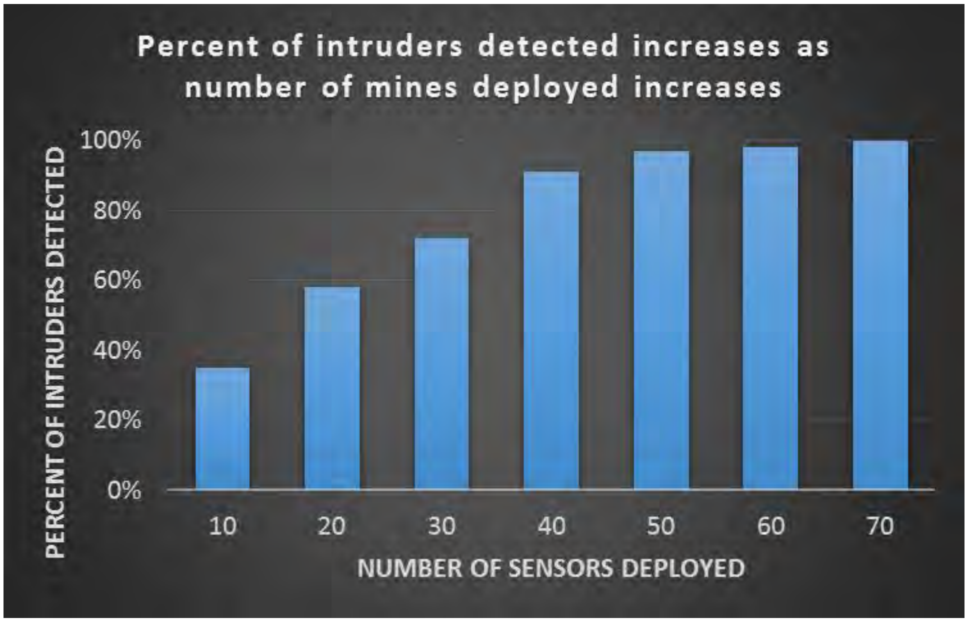


Figure 56. Intruder Detection as a Function of the Number of Sensors Deployed

Additionally, higher sensor capability in the form of a larger detection range results in a requirement for fewer sensors to maintain a given level of detection. The effects of changes to detection ranges are shown in Figure 57. Once again, the only parameter altered is the sensor detection range. All other parameters remain the same as in Figure 52.

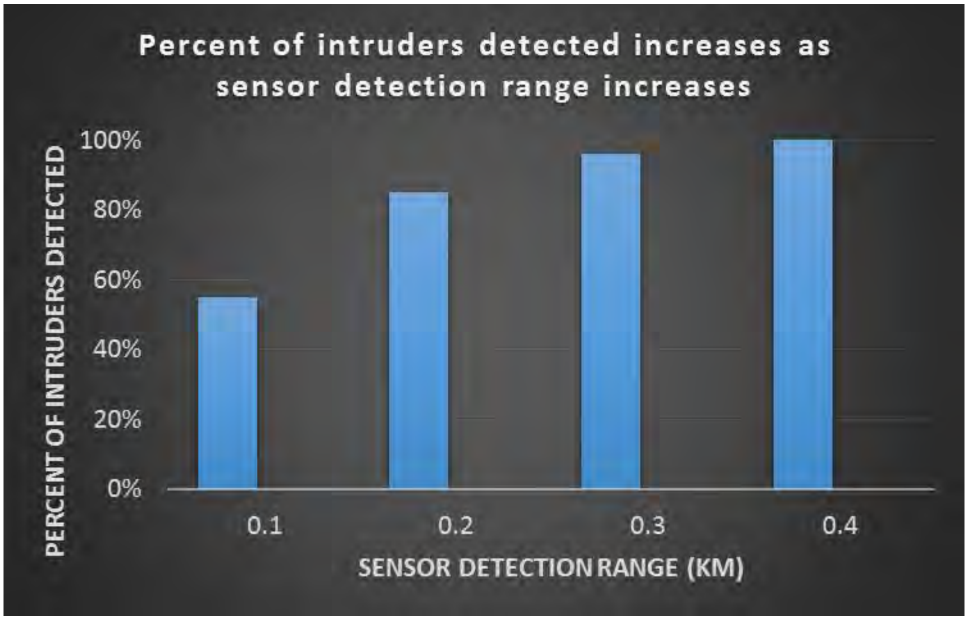


Figure 57. Intruder Detection as a Function of Sensor Detection Range

9. Sea Transit Through Blockade or Quarantine

A discrete Monte Carlo simulation was created to enable analysis of the impacts of various levels of speed and stealth on the success of a blue force supply ship transiting through a sea blockade placed around the island by red forces. This model was based on work presented by Professor James Eagle (Eagle, 1). It allows the user to input the following:

- Barrier width
- Search traversal speed across the barrier
- Searcher detection radius
- Blockade runner transit speed
- Time between discrete simulation steps

The model itself works by moving the searcher on the x axis according to the input speed and the time between discrete steps. The runner is placed at some location on the x-axis at a distance from the actual barrier and moves towards the barrier based on the searcher traversal speed and time between the simulation steps. The distance between the searcher and the runner is measured at each step, and the runner is counted as having been detected if that distance is less than the searcher detection radius. The assumption is

made that the searcher has a probability of detection of 100% for any contact that is within its detection radius.

Table 26 depicts runner success as a function of runner and searcher speeds. Preliminary analysis indicates that the runner is more likely to successfully run the blockade when it has a large speed advantage over the searcher. Table 27 depicts runner success as a function searcher speed and detection range. Preliminary analysis indicates that a runner that is detectable at longer ranges is less likely to successfully make it through the blockade than a runner that can only be detected at short range. For both tables, the percentage in each cell represents the percent of simulation runs in which the runner was detected. Two thousand simulation runs were performed for each speed combination in each table.

Table 26. Monte Carlo Simulation Output for Searcher Speed versus Runner Speed

Probability of detection as a function of searcher speed and runner speed

Searcher Speed \ Runner Speed	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	49%	27%	18%	13%	10%	8%	7%	8%	6%	5%	5%	5%	5%	4%	3%	3%	3%	3%
10	50%	47%	35%	25%	23%	17%	15%	13%	11%	11%	9%	9%	7%	8%	6%	6%	6%	6%
15	48%	44%	47%	38%	30%	25%	22%	19%	18%	16%	12%	13%	12%	11%	10%	10%	8%	8%
20	45%	44%	49%	48%	42%	32%	28%	28%	23%	22%	17%	18%	15%	15%	13%	12%	12%	13%
25	46%	45%	49%	48%	46%	42%	37%	34%	29%	25%	21%	23%	20%	20%	17%	17%	15%	15%
30	46%	47%	49%	50%	48%	48%	42%	38%	34%	29%	29%	26%	24%	23%	20%	19%	19%	16%
35	46%	48%	48%	48%	47%	47%	48%	45%	40%	34%	35%	30%	28%	28%	26%	24%	22%	18%
40	45%	49%	48%	46%	50%	47%	47%	46%	42%	40%	38%	33%	30%	29%	27%	24%	25%	23%
45	47%	47%	46%	49%	47%	45%	50%	45%	47%	44%	43%	39%	33%	32%	30%	28%	26%	27%
50	46%	48%	49%	49%	47%	43%	48%	44%	48%	47%	44%	42%	39%	37%	35%	32%	31%	30%
55	46%	48%	45%	47%	49%	45%	48%	45%	46%	47%	45%	45%	44%	39%	37%	35%	33%	31%
60	47%	49%	46%	45%	49%	45%	49%	47%	45%	46%	44%	47%	46%	44%	42%	37%	37%	35%
65	43%	44%	47%	50%	48%	45%	48%	45%	43%	49%	46%	46%	47%	45%	43%	41%	38%	37%
70	44%	48%	47%	47%	48%	46%	50%	49%	45%	47%	45%	47%	47%	48%	45%	45%	40%	40%
75	45%	46%	50%	48%	49%	45%	50%	49%	45%	47%	46%	44%	46%	48%	47%	45%	43%	42%
80	45%	46%	47%	47%	48%	48%	50%	48%	45%	47%	46%	47%	46%	47%	46%	45%	44%	44%
85	45%	47%	48%	47%	48%	46%	48%	49%	45%	47%	47%	45%	44%	47%	46%	47%	47%	45%
90	45%	45%	49%	47%	46%	48%	46%	48%	46%	46%	48%	48%	45%	48%	47%	46%	46%	47%

Table 27. Monte Carlo Simulation Output for Searcher Speed versus Detection Range

Probability of detection as a function of searcher speed and detection range

Searcher Speed \ Detection Range	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
5	5%	10%	16%	23%	29%	34%	41%	49%	54%	60%	64%	71%	75%	79%	85%	88%	92%	93%
10	8%	18%	28%	37%	47%	53%	60%	68%	74%	81%	86%	89%	92%	94%	98%	99%	100%	100%
15	8%	20%	29%	39%	51%	55%	61%	69%	76%	83%	89%	90%	94%	95%	98%	100%	100%	100%
20	9%	20%	29%	40%	47%	55%	60%	70%	75%	81%	85%	89%	92%	95%	98%	99%	100%	100%
25	10%	20%	31%	38%	48%	54%	63%	68%	71%	77%	82%	86%	89%	95%	98%	99%	100%	100%
30	9%	18%	30%	38%	46%	54%	61%	65%	71%	75%	81%	82%	88%	93%	97%	99%	100%	100%
35	8%	20%	30%	37%	48%	52%	60%	65%	66%	75%	79%	82%	88%	92%	96%	99%	100%	100%
40	8%	19%	30%	38%	48%	50%	56%	65%	68%	72%	78%	80%	87%	91%	96%	99%	100%	100%
45	9%	19%	30%	36%	47%	51%	56%	63%	66%	70%	77%	80%	86%	90%	95%	98%	100%	100%
50	9%	19%	29%	39%	45%	50%	56%	62%	67%	72%	75%	79%	83%	90%	93%	98%	100%	100%
55	10%	17%	28%	38%	44%	51%	54%	61%	65%	71%	75%	77%	84%	88%	93%	97%	100%	100%
60	9%	17%	28%	37%	45%	51%	53%	62%	66%	69%	75%	77%	83%	87%	93%	98%	100%	100%
65	8%	19%	28%	36%	46%	51%	53%	58%	65%	67%	72%	78%	83%	88%	92%	97%	99%	100%
70	9%	18%	27%	38%	44%	49%	53%	60%	65%	70%	73%	79%	82%	87%	92%	97%	100%	100%
75	9%	17%	26%	38%	45%	48%	54%	59%	63%	69%	74%	77%	82%	87%	92%	96%	99%	100%
80	7%	17%	28%	35%	44%	47%	54%	56%	63%	68%	74%	77%	81%	87%	91%	96%	100%	100%
85	9%	19%	27%	34%	44%	47%	54%	58%	63%	68%	72%	76%	82%	86%	92%	95%	99%	100%
90	9%	19%	27%	36%	42%	48%	53%	57%	63%	68%	71%	77%	82%	86%	91%	96%	100%	100%

10. Logistics Requirements

Logistics requirements were tallied using information using a variety of sources. The Logistics Planning Factors were used to determine the consumption of the following items by similar units:

- Water – 7.4 gallons per person per day for hot climates
- Fuel – varies based on number of vehicles used
- Clothing – 2.1 pounds per day
- Barrier materials – 8.1 pounds per person per day
- Medical supplies – 2.4 pounds per person per day
- Personal demand – 3.4 pounds per person per day

High, mid-level, and minimum requirements were calculated for assault and sustainment scenarios. Supply requirements for situations in which water was supplied and created on-site were analyzed.

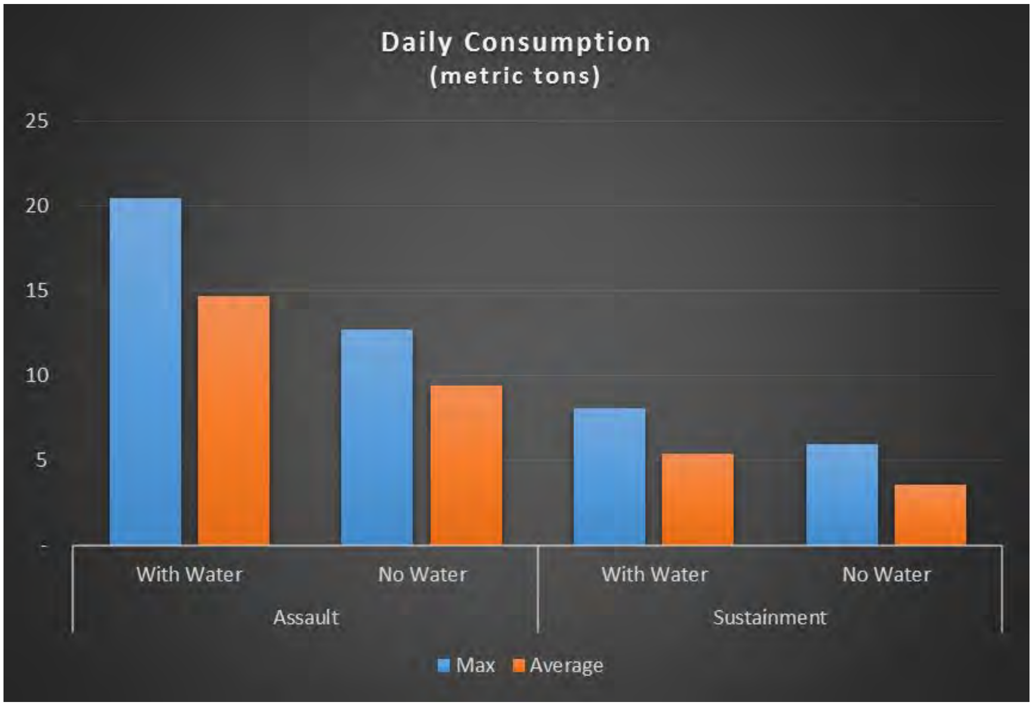


Figure 58. Daily Consumption Excluding Electrical Generator Fuel

Additional fuel requirements were determined based on electricity generation using diesel generators. The amount of energy required (in kilowatt hours) was calculated based on data from the 2008 CENTCOM Sandbook and 249th Engineering Battalion Interviews (Varin 2010). There was a wide variation between these two sources; individual power requirements ranged from 0.7 to 3.7 kilowatts per day. For usages calculated in Table 28, the assumption was made that the overall power requirement would be equivalent to 12 hours of full power draw. Table 29 followed-up by determining fuel consumption given such electrical requirements.

Table 28. Electrical Energy Consumption Estimates

	Source	kW per person	Company (150)	Scenario (200)	kWh Used (12 hours)	Scenario monthly (kWh)
Low	CENTCOM Sand Book, 2008	0.7	105	140	1,680	50,400
Mid	Averaged	2.2	330	440	5,280	158,400
High	249th ENGR BN Interviews	3.7	555	740	8,880	266,400

Table 29. Generators Identified for Determining Fuel Consumption

Generators	Fuel Consumption (GPH)
MEP 012A 750kW	55
MEP 806A/B 60kW, 60/400Hz	4.6
MEP 805A/B 30kW, 60Hz	2.6

Table 30 shows that dividing the kilowatt value for each generator by the fuel consumption value results in an average value for fuel consumption per kilowatt hour.

Table 30. Average Fuel Consumption per Kilowatt-Hour

Generators	kW/GPH
MEP 012A 750kW	13.6
MEP 806A/B 60kW, 60/400Hz	13.0
MEP 805A/B 30kW, 60Hz	11.5
average	12.7

Using the average value from Table 30, an estimate for the amount of fuel needed in order to meet daily electrical generation requirements can be determined, as shown in Table 31.Table 31.

Table 31. Daily Electrical Energy Sustainment Fuel Requirements

Source	kWh Used (12 hours)	Fuel Required (gal)	Fuel Required (m-tons)
CENTCOM Sand Book, 2008	1,680	132	0.49
Averaged	5,280	414	1.53
249th ENGR BN Interviews	8,880	697	2.58

Combinations of generator units were combined to meet the energy requirements as dictated above. Fuel consumption values were then added to the LPF requirements above to determine overall fuel requirements. Figure 59 shows fuel requirements (including mid-level power generation use) combined requirements from the Logistics Planning factors. This information was used to determine the rate at which supplies would need to be delivered to the island in order to sustain the deployed forces.

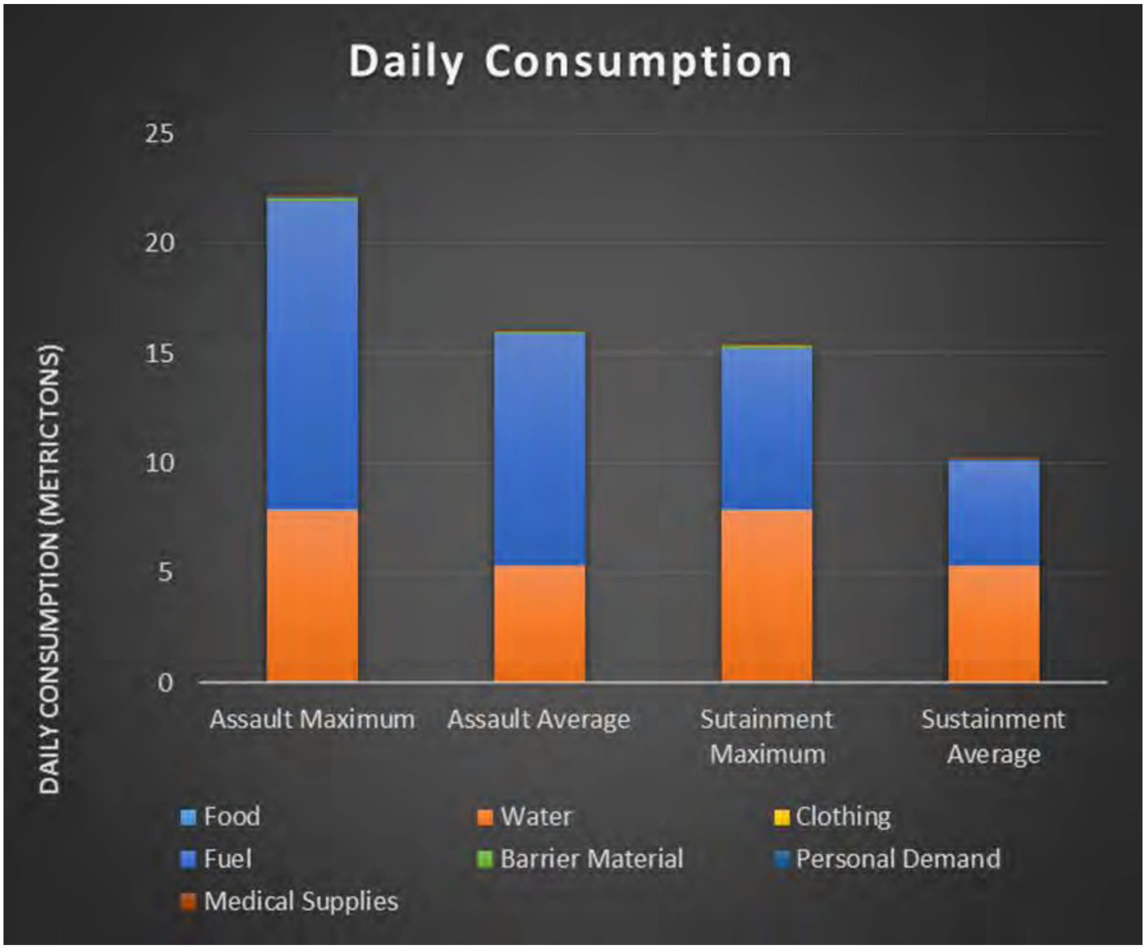


Figure 59. Daily Consumption Including Electrical Generator Fuel

XII. CONCLUSION

A. SOME INSIGHTS

The *Capstone Concept for Joint Operations: Version 3.0* was published in 2009 and it details a vision for the future of joint operations. We believe that our system of systems achieves the "implications of adopting this concept" outlined in the report (Mullen 2009). Some elements of this report follow from which we make our case for validating the SOS we have constructed.

Build a balanced and versatile joint force (Mullen 2009). Our concept includes a range of equipment and personnel from across the DOD. It includes, but is not restricted to, Army, Navy and Air Force. Several varieties of mission packages are available and interchangeable based on the mission's requirements and the commander's intent. Where speed is required above all else, the Army/Air Force package can deliver equipment that has both anti-air and anti-surface capability.

Institute mechanisms to prepare general-purpose forces quickly for mission changes (Mullen 2009). Our concept can be expanded or contracted as the mission dictates. The capability of the delivery systems to provide initial force packages and resupply means that more than one location can be serviced by resupply efforts. This means that several locations can be maintained simultaneously. The JHSV, for example, can deliver more than three weeks' worth of supplies to one location or one week's worth of supplies to three locations. Likewise, a single C-17 sortie can provide more than three days' worth of supplies to one location and supplying three locations could be accomplished by one sortie per day.

Improve knowledge of and capabilities for waging irregular warfare (Mullen 2009). Our force is will be tasked with a mission that has not been required since the end of World War II. They may be asked to occupy, hold, monitor and defend sea and air space around an island or any other territorial claim against a potential adversary. They may need to be both a deterrent by presence and a deterrent by force.

Create agile general-purpose forces capable of operating independently at increasingly lower echelons (Mullen 2009). One of our goals was to create a force that fit the need while maintaining a high level of indigenous capability. This lead to the conclusion that several systems were needed to bolster our forces ability to detect and target enemy forces. The repurposing of the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS), or even the Army's RAID (Rapid Aerostat Initial Deployment) tower, helps to fulfill the need for an autonomous ISR capability and makes use of items already in our inventory. Our current inventory of weapons does not include a land based anti-ship missile system, thus we have recommended the use of the NSM to provide our deployed force with the ability to operate and defend at the unit level.

Maintain the capability to project and sustain military power over global distances (Mullen 2009). Our system of systems has the ability to be rapidly deployed using multiple services air transport capabilities. Naturally, the Army/Air Force COA has the longest reach in the least amount of time. Once the equipment is assembled and staged, the time to deploy is a matter of hours instead of days or weeks.

Improve capabilities and capacities for covert and clandestine operations (Mullen 2009). The need to be the first to arrive has only one key requirement: that you get there first. When the physical limits of time and distance are not in your favor then consideration must be given to deciding to move before an adversary makes their final decision. The ability to deliver troops covertly prevents the enemy from moving the timeline forward as a reaction to more overt signs that a mission to deploy forces is underway. As General Martin E. Dempsey stated:

> The reality of force development is that about 80% of Joint Force 2020 is programmed or exists today. We do, however, have an opportunity to be innovative in two ways. We can significantly change the other 20% of the force, and we can change the way we use the entire force. While new capabilities will be essential, many of our most important advancements will come through innovations in training, education, personnel management, and leadership development. (Dempsey 2012)

The Capstone Concept for Joint Operations: Joint Force 2020, a 2012 publication by the U.S. Joint Chiefs of Staff examined the concept of Globally Integrated Operations in detail. These were some explicitly pertinent statements from that publication:

- Globally Integrated Operations requires a commitment to mission command
- Globally Integrated Operations must provide the ability to seize, retain and exploit the initiative in time and across domains
- Globally Integrated Operations both enable and are premised upon global agility
- Globally Integrated Operations place a premium on partnering
- Globally Integrated Operations provide for more flexibility in how Joint Forces are established and employed
- Future Joint Forces will leverage better integration to improve cross-domain synergy
- Flexible, low-signature or small-footprint capabilities such as cyberspace, space, special operations, global strike, and ISR will play more pronounced roles in future joint operations (Dempsey 2012)

In the current fiscal environment, with the threats facing the United States and its allies, options are limited. Joint efforts and force tailoring are essential to accomplish some of the new missions presenting themselves. This project succeeded in establishing concepts, models, and recommendations for the flexible, global integration sought in the preceding points.

There are several facets of modern strategy that are confirmed in our analysis. For example, we know that stealth will reduce reaction time; this is why we found detectability to be a key measure for effectiveness. As a counter, we know that possessing significant speed requires aircraft, and this impacts decision making on the importance of the speed of one's own force weighed against the opponent's reaction time. The cheapest option is slow, and knowing this makes the decision tougher for leaders, knowing they must strike a balance between effectiveness and cost.

Do we need a land force equipped with extensive supplies or heavy defensive systems? Heavy cargo lift requires large airplanes or very slow ships. ARGs are good for middle of the road in cost and speed, but can deliver large amounts of cargo. As such, ARGs have served this nation well, but may not be sufficiently effective in or near an A2AD environment when the risks are weighed.

The tools for force shaping geared towards these types of problems are available. Here we have created several models and one tool particularly tailored for decision making. We believe we know our enemy. It is only through also having self-knowledge that we can achieve victory. A decision making tool such as the one we have made required that self-knowledge because a leader must set priorities. The risks and rewards should become clear once that is complete.

We found through analysis that Air Force C-17s and C-130s are the best options for delivery of an expeditionary force when considering average performance ability across the entire range of inputs we explored. It is possible for individual leader inputs to change the most favorable anticipated outcomes based on reconfiguration of MOE weights on a case-by-case basis. Such priority-result sets were detailed in Chapter XI and Appendix F. In representing our stakeholders, our team found speed to be the top priority. Therefore, to accomplish the given mission we submit for recommendation a force package that utilizes COA E (Air Force C-17 and C-130) aircraft deployment of land force packages COA 6 for small islands or COA 8 for large islands.

In Chapter VII, we stated that within the DOD the ability to network and pull disparate systems together quickly, in order to seize an island, does not exist. Our team followed through on its promise to examine this current gap in capability integration and prove that there are a set of existing capabilities within DOD, as a whole, to accomplish the mission of quickly seizing an island before an opponent. After all that we have discovered through exploratory analysis, not only do we highly recommend, we implore the DOD to make plans to seize small island areas on short notice in the A2AD environment using existing capabilities integrated for a short-notice flexible response.

APPENDIX A. U.S. NAVY-MARINE CORPS TASK LIST

No.	Task Name	Description
1	A.0	Amphibious Tasks
2	MCT.0	Marine Tasks
3	MCT.1.0	Conduct Maneuver
4	MCT.1.3	Conduct Maneuver and Close Forces
5	MCT.1.3.5	Navigate
6	MCT.1.4	Deploy Conduct Maneuver (marines)
7	MCT.1.4.1	Conduct Mobility Operations
8	MCT.1.4.2	Conduct Breaching Operations
9	MCT.1.4.2.1	Breach Enemy Defensive Positions
10	MCT.1.4.2.3	Breach Barriers and Obstacles
11	MCT.1.6	Dominate the OPAREA
12	MCT.1.6.1	Conduct offensive operations
13	MCT.3.0	Employ Firepower (marines)
14	MCT.3.2	Attack Targets (marines)
15	MCT.3.2.1	Conduct Fire support tasks
16	MCT.4.0	Perform Logistics and Combat Service Support (marines)
17	MCT.4.1	Conduct Supply Operations
18	MCT.4.1.1	Conduct Aviation Supply Operations
19	MCT.4.1.2	Conduct Ground Supply Operations
20	MCT.4.3	Conduct Transportation Operations
21	MCT.4.3.1	Conduct Embark Support
22	MCT.4.3.2	Conduct Port Support
23	MCT.4.3.3	conduct Motor Transport
24	MCT.4.3.4	Conduct Air Delivery Operations
25	MCT.5.0	Exercise Command and Control (marines)
26	MCT.5.1	Acquire, Process, Communicate info
27	MCT.5.1.1	Provide and Maintain Communications
28	MCT.5.1.2	Provide Means of Communicating Information
29	MCT.5.2	Prepare Plans and Orders
30	MCT.5.2.1	Conduct Rapid Response and Planning Process
31	MCT.5.3	Direct, Lead, Coordinate Forces and Operations
32	MCT.5.3.1	Direct Operations
33	MCT.5.3.2	Establish means to command and control
34	NTA.0	Naval Tasks
35	NTA.1.0	Deploy/Conduct Maneuver
36	NTA.1.1	Move Naval Tactical Forces
37	NTA.1.1.1	l Prepare Forces for Movement
38	NTA.1.1.1.1	Identify Lift Requirements
39	NTA.1.1.1.2	Stage Marshal Forces
40	NTA.1.1.1.3	Embark Forces
41	NTA.1.1.1.5	Conduct Shore-to-Ship Movement

42	NTA.1.1.1.7	Prepare Ship for Movement
43	NTA.1.1.1.7.1	Provide Engineering/Main Propulsion
44	NTA.1.1.1.7.2	Provide Combat Systems/Deck/Coms
45	NTA.1.1.1.7.3	Provide Damage Control
46	NTA.1.1.2	Move Forces
47	NTA.1.1.2.2	Move Embarked Forces
48	NTA.1.1.2.3	Move Units
49	NTA.1.1.2.3.1	Conduct Sail Ship from port
50	NTA.1.1.2.3.3	Conduct Flight Operations
51	NTA.1.1.2.3.4	Conduct Convoy Operations
52	NTA.1.1.2.3.5	Conduct Well Operations
53	NTA.1.1.2.3.7	Conduct small boat operations
54	NTA.1.1.2.3.8	Conduct Submerged Operations
55	NTA.1.1.2.4	Conduct Tactical Insertion and Extraction
56	NTA.1.1.2.5	Conduct Employ Remove Vehicles
57	NTA.1.2	Navigate and close forces
58	NTA.1.2.1	Establish Force area operations
59	NTA.1.2.1.1	Establish Plan for Water Space management
60	NTA.1.2.1.2	Conduct Air Space Management and Control
61	NTA.1.2.1.3	Establish Amphibious Objective areas
62	NTA.1.2.1.5	Determine Command Relationship for the Force
63	NTA.1.2.2	Stage Forces
64	NTA.1.2.4	perform surf Observations
65	NTA.1.2.5	Conduct Terrain Analysis
66	NTA.1.2.6	Conduct Meteorological Analysis
67	NTA.1.2.8	Conduct Tactical recon/surveillance
68	NTA.1.2.8.1	Conduct route and road reconnaissance
69	NTA.1.2.8.2	Conduct Helicopter Landing Zone Reconnaissance
70	NTA.1.2.8.3	Conduct Airborne Recon/Surveillance
71	NTA.1.2.10	Conduct Beach Party Operations
72	NTA.1.2.11	Conduct Navigation
73	NTA.1.2.12	Maneuver in Formation
74	NTA.1.3	Maintain Mobility
75	NTA.1.3.1	Perform Mine Countermeasures
76	NTA.1.3.1.1	Conduct Mine Hunting
77	NTA.1.3.1.2	Conduct Mine Sweeping
78	NTA.1.3.2	Conduct Breaching of Minefields and Barriers
79	NTA.1.3.2.1	Mark Barriers and Obstacles
80	NTA.1.3.2.2	Clear Minefields / Barriers / Obstacles
81	NTA.1.3.2.3	Transit Mine Threat Areas
82	NTA.1.3.3	Enhance Force Mobility
83	NTA.1.4	Conduct Counter-Mobility
84	NTA.1.4.5	Conduct Blockade
85	NTA.1.4.6	Conduct Maritime Interception
86	NTA.1.4.6.4	Escort Detained Vessels

87 NTA.1.4.6.5 Stop and/ or Neutralize Noncompliant Actors
88 NTA.1.4.7 Enforce Exclusion Zone
89 NTA.1.5 Dominate the Operational Area
90 NTA.1.5.1 Dominate the Area through Employment of Combat Systems
91 NTA.1.5.1.1 Maneuver Naval Forces
92 NTA.1.5.1.2 Occupy Battlespace
93 NTA.1.5.1.3 Integrate Forces
94 NTA.1.5.2 Conduct Amphibious Operations
95 NTA.1.5.2.1 Conduct Ship-to-Shore / Objective Maneuver
96 NTA.1.5.2.2 Conduct Amphibious Assault
97 NTA.1.5.2.2.1 Conduct Forcible Entry in AOR
98 NTA.1.5.2.2.2 Seize and Hold Lodgment
99 NTA.1.5.2.2.3 Build up the force
100 NTA.1.5.2.2.4 Stabilize the Lodgment
101 NTA.1.5.2.2.5 Insert Follow-on Forces
102 NTA.1.5.2.4 Conduct an Amphibious Withdrawal
103 NTA.1.5.3 Conduct Attack
104 NTA.1.5.4 Conduct Security
105 NTA.1.5.4.1 Conduct Screen
106 NTA.1.5.4.2 Conduct Cover
107 NTA.1.5.4.3 Provide Area Security
108 NTA.1.5.4.4 Secure an Area
109 NTA.1.5.5 Conduct Ground Tactical Enabling Operations
110 NTA.1.5.7 Conduct Naval Special Warfare
111 NTA.1.5.8 Conduct Unconventional Warfare
112 NTA.1.5.9 Conduct Information Superiority
113 NTA.3.0 Employ Firepower
114 NTA.3.1 Process Targets
115 NTA.3.1.1 Request Attack
116 NTA.3.1.2 Select Target to Attack
117 NTA.3.1.4 Develop Order to Fire
118 NTA.3.2 Attack Targets
119 NTA.3.2.1 Attack Enemy Maritime Target
120 NTA.3.2.1.1 Attack Surface Targets
121 NTA.3.2.2 Attack Land Targets
122 NTA.3.2.2.1 Attack Submerged Target
123 NTA.3.2.3 Attack Enemy Aircraft and Missiles
124 NTA.3.2.4 Suppress Enemy Air Defenses (SEAD)
125 NTA.3.2.5 Conduct Electronic Attack
126 NTA.3.2.5.1 Conduct C2 Attack
127 NTA.3.2.6 Interdict Enemy Operational Forces
128 NTA.3.2.7 Intercept, Engage, and Neutralize Enemy Aircraft
129 NTA.3.2.8 Conduct Fire Support
130 NTA.3.2.8.1 Organize fire support assets

131	NTA.3.2.8.2	Illuminate/Designate Targets
132	NTA.3.2.8.3	Engaged Targets
133	NTA.3.2.8.4	Adjust Fires
134	NTA.4.0	Perform Logistics and Combat Service Support
135	NTA.4.1	Arm
136	NTA.4.1.1	Schedule Armament of Task Force
137	NTA.4.1.2	Provide Munitions Management
138	NTA.4.1.4	Maintain Explosive Safety
139	NTA.4.1.5	On-Load and Off-Load Ordnance
140	NTA.4.2	Fuel
141	NTA.4.2.1	Conduct Fuel Management
142	NTA.4.2.1.1	Schedule Refueling
143	NTA.4.2.2	Move Bulk Fuel
144	NTA.4.4	Provide Personnel and Personnel Support
145	NTA.4.4.1	Distribute Support and Personnel
146	NTA.4.4.1.2	Provide Personnel Accounting and Strength Reporting
147	NTA.4.4.1.3	Provide Replacement Personnel Management
148	NTA.4.4.2.2	Provide Food Services
149	NTA.4.5	Provide Transport
150	NTA.4.6	Supply the Force
151	NTA.4.6.1	Provide General Supply Support
152	NTA.4.6.3	Provide Underway Replenishment
153	NTA.4.6.5	Provide Vertical Replenishment
154	NTA.4.6.6	Provide Air Delivery
155	NTA.5.0	Exercise Command and Control
156	NTA.5.1	Acquire, Process, Communicate Information and Maintain Status
157	NTA.5.1.1	Exercise Command and Control 2
158	NTA.5.1.2	Manage Means of Communicating Information
159	NTA.5.1.3	Maintain and Display Unit Readiness
160	NTA.5.1.4	Exercise Command and Control 5
161	NTA.5.1.5	Exercise Command and Control 6
162	NTA.5.2	Analyze and Assess Situation
163	NTA.5.2.1	Analyze Mission and Current Situation
164	NTA.5.2.1.3	Review ROE
165	NTA.5.2.1.5	Exercise Command and Control 10
166	NTA.5.3	Exercise Command and Control 11
167	NTA.5.3.1	Develop Concept of Operations
168	NTA.5.3.2	Issue Planning Guidance
169	NTA.5.3.3	Develop Course of Action
170	NTA.5.3.6	Prioritize Subordinate Command Requirements
171	NTA.6.0	Protect the Force
172	NTA.6.1	Enhance Survivability
173	NTA.6.1.1	Protect against combat area hazards
174	NTA.6.1.1.2	Remove Hazards
175	NTA.6.1.1.3	ID Friendly Forces

176 NTA.6.1.6 Protect the Environment
177 NTA.6.3 Provide Security for Operational Forces and Means
178 NTA.6.3.1 Protect and Secure OPAREA

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APPENDIX B. U.S. NAVY PLATFORMS

A. SSGN

Figure 60. SSGN. Image from "Jane's" 2015

- Converted Ohio class ballistic missile submarine that has been converted into a cruise missile submarine.
- Cruise missiles: Up to 154 Raytheon Tomahawk Block III and Block IV
- Torpedoes: 4 bow tubes capable of firing Mk 48 ADACPs
- Unit Cost: 4 billion (Estimate)

Table 32. SSGN Specifications (after Jane's 2015)

Length Overall	170.7 m
Beam	12.8 m
Draught	11.1 m
Top speed	25 kts
Crew	174
SOF	66 for 90 days or 102 for approx. 14 days
Range	Unlimited

B. MH-60S “SIERRA”

Figure 61. MH-60S “Sierra” (from Jane’s 2015)

- Helicopter that is capable of performing a wide range of maritime missions and can be deployed on the LCS
- Unit Cost: 20.7 million (Balle 2014)

Table 33. MH-60S Specifications (after MH-60 2015)

Max. takeoff gross weight	23,500 lbs
Maximum useful load	9,070 lbs
Dash speed	153 kts
Approximate range	245 NM
Engines	(2) T700-GE-401C
Weapons	7.62 mm and 50 cal. guns
Maximum cabin seats	14
Auxiliary fuel	Up to two external tanks

C. JOINT HIGH SPEED VESSEL

Figure 62. Joint High Speed Vessel (from Jane's 2015)

- Contains either 150 troops in berths or 312 troops in airline style seating
- Landing ramp can support M1A2 Abrams tank
- Flight Deck is CH-53E Capable
- Unit Cost: 185 million ("JHSV" 2014)

Table 34. JHSV Specifications (after Jane's 2015)

Length Overall	103 m
Beam	28.5 m
Draught	3.8 m
Crew	41
Payload	635 MT
Range	1200 NM at 35 kts

D. LITTORAL COMBAT SHIP INDEPENDENCE CLASS (LCS)

Figure 63. LCS Independence Class (from Jane's 2015).

- Accommodates mission module change-out ability
- Large Mission Bay (15,200 square feet)
- Can support any mission with a reserve module onboard
- Unit Cost: 440 million (O'Rourke 2014)

Table 35. Independence LCS Specifications (after Jane's 2015)

Length Overall	127.4 m
Beam	31.6 m
Draught	4.27 m
Crew (Core)	40
Crew (Mission)	35
Payload	210 MT
Range	4300 NM at 18 kts
Max Speed	40+ knots

E. LITTORAL COMBAT SHIP FREEDOM CLASS

Figure 64. LCS Freedom Class (from Jane's 2015).

- Accommodates mission module change-out ability
- Transports three 11m RHIB capable of supporting transport of 30 passengers per trip
- Aircraft: 2 SH-60(R&S)
- Unit Cost: 440 million (O'Rourke 2015)

Table 36. Freedom LCS Specifications (after Jane's 2015).

Length Overall	115 m
Beam	17.5 m
Draught	3.9 m
Crew (Core)	50
Crew (Mission)	15
Endurance	21 Days
Range	3500 NM at 18 kts
Max Speed	45+ knots

F. LANDING CATAMARAN (L-CAT)

Figure 65. French Landing Catamaran (from Jane's 2015).

- Fast landing craft capable of docking with LPD and LHD
- Transports personnel, vehicles and equipment
- Unit Cost: 16.5 million ("Shifting" 2011)

Table 37. L-CAT Specifications (after LCAT 2014).

Length Overall	30 m
Beam	12.6 m
Draught	0.6 m
Crew (Core)	4-8
Crew (Mission)	40
Load capacity	80 tons
Range	430 NM (loaded) 600 NM (light)
Speed	30 kts (light) 18 kts (loaded)

G. MV-22 OSPREY

Figure 66. MV-22 Osprey (from V22 n.d.)

- Tiltrotor aircraft capable of vertical take-off/landing.
- Can accommodate up to 24 troops.
- Unit Cost: 72 million ("Budget" 2014)

Table 38. MV-22 Specifications (after V-22 n.d.).

Max. Vertical takeoff gross weight	53,600 lbs
Maximum useful load	19,141 lbs
Cruise speed	280 kts
Mission radius (extra tank)	242 NM
Engines	(2) AE 1107C
Crew	2-3
Maximum cabin seats	14
Auxiliary fuel	Up to one external tank

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APPENDIX C. U.S. MARINE CORPS PLATFORMS

A. PATRIOT MISSILE

Figure 67. Patriot Missile (from Jane's 2014)

Table 39. Patriot Missile Specifications

Cost	$30.44M per Battery
Weight	10,000 lbs per Battery
Range	52 NM (96 km) for PAC-2
Number of missiles per battery	4

B. NAVAL STRIKE MISSILE (NSM)

Figure 68. Naval Strike Missile (from Jane's 2014)

Table 40. NSM Specifications (after Strike 2015)

Cost	$12.6 M per Battery
Weight	51,600 lbs per Battery
Range	62 NM (115 km)
Number of missiles per battery	4
Speed	High Subsonic

.

C. AVENGER

Figure 69. Avenger (from Boeing n.d.)

Table 41. Avenger Specifications (after Avenger n.d.)

Cost	$652,000 per Battery
Weight	8,600 lbs per Battery
Missile Range	4.3 NM (8 km)
Number of missiles per battery	4-8
Missile Speed	Supersonic

D. JLENS

Figure 70. JLENS

Table 42. JLENS Specifications (after JLENS 2015).

Range	296 NM (340 mi) (horizontal), 15,000 ft (vertical)
Operation	Fiber optic cable
Weight	7000 lbs

E. GIRAFFE AMB

Figure 71. Giraffe AMB (from Wolff n.d. [b]).

Table 43. Giraffe AMB Specifications (after Wolff n.d.[b])

Range	54 NM (62 mi) (horizontal), 60,000 ft (vertical)
Operating frequency	C-band (5.4-5.9 GHz)
Weight	550 lbs

F. AN/TPS-80

Figure 72. AN/TPS-80 Radar (from GATOR 2015).

Table 44. AN/TPS-80 Radar Specifications (after GATOR 2015)

Range	Estimated 139 NM (160 mi), as it is a replacement for 5 radars: TPS-63 (air defense), TPS-73 (air-traffic control), MPQ-62 (short range air defense), TPQ-46 (counter-fire target acquisition), and the UPS-3 (target tracking)
Operating frequency	S-band (2–4 GHz)
Weight	8500 lbs
Airlift	Three CH-53E or one MV-22B or one C-130
Operating temperature	-40ºC to +55ºC
Setup time	45min

G. AN/MPQ-53

Figure 73. AN/MPQ-53 Radar (from Wolff n.d. [a]).

Table 45. An/MPQ-53 Radar Specifications (after Wolff n.d. [a]).

Range	92 NM (170 mi)
Operating frequency	C-band (4-8 GHz)
Weight	5667 lbs

H. MQ-1 PREDATOR

Figure 74. MQ-1 Predator (from Jane's 2014)/

Table 46. MQ-1 Predator Specifications (after Predator 2010).

Range	669 NM (770 mi)
Ceiling	25,000 ft
Speed	261 kts (300 mph)
Weight	5667 lbs

I. RQ-7 SHADOW

Figure 75. RQ-7 Shadow (from Jane's n.d.)

Table 47. RQ-7 Shadow Specifications (after Shadow 2015)

Range	59 NM (68 mi)
Ceiling	15,000 ft
Speed	90 kts (103 mph)
Weight	375 lbs

J. REMUS 600

Figure 76. REMUS 600 (REMUS 2015)

Table 48. REMUS 600 Specifications (after REMUS 2015)

Vehicle diameter	12.8 in (32.4 cm)
Vehicle length	10.7 ft (3.25 m)
Weight in air	529 lbs (240 kg)
Trim weight	2.2 lbs (1 kg)
Maximum operating depth	1969 feet (600 m)
Energy	5.2 kWh rechargeable lithium ion battery
Endurance	Typically 24h dependent on speed and sensor configuration, operating environment and mission program
Propulsion	Direct drive DC brushless motor to open two bladed propeller
Velocity Range	Up to 4 kts (2.1m/s)
Transponders	9-16 kHz operating frequency range
Navigation	Navigation Processor, Inertial navigator, Long Baseline (LBL) acoustic, WAAS GPS
Sensors	Acoustic Doppler Current Profiling, Inertial Navigation System, Pressure Conductivity and Temperature, Depth, GPS

K. QUADCOPTER (MICRODRONE MD4-200)

Figure 77. Quadcopter (Microdrone md4-200) (from Microdrones 2015)

Table 49. Quadcopter (Microdrone md4-200) Specifications (sfter Microdrones 2015)

Rate of climb	10 kts (5.0 m/s)
Operating speed	984 ft/min (5.0 m/s)
Maximum thrust	15.5 N
Weight	1.8 lbs (800 g)
Recommended load	0.44 lbs (200 g)
Maximum load	0.55 lbs (250 g)
Maximum take-off weight (MTOW)	2.3 lbs (1,050 g)
Dimensions	540 mm (from rotor hub to rotor hub)
Flying time	Up to 30 minutes (depending on load/ wind/battery)
Battery	14.8 V, 4S LiPo, 2300 mAh
Flat core motors	yes
CFD optimized propeller	yes
Closed carbon housing	yes
IP43 protection	yes

L. LOGISTICS

Logistics costs are estimated based on fixed assets and consumable supplies.

(a) Fixed assets include generators, transport vehicles, handheld and vehicular communication systems, and tools for the combat engineers. These assets are brought in via a one-time effort at the beginning of the mission.

The cost of an equipped HMMWV is estimated at $220,000 ("HMMWV," 2011). The costs of the generators, tools for the combat engineers and the Communications equipment have been estimated based on similar units.

Table 50. Costs of Fixed Assets

Fixed Assets	Costs
Generators	$ 162,000.00
Vehicles	$ 2,200,000.00
Tools for combat engineers	$ 500,000.00
Communication Equipment	$ 2,000,000.00
Total	$ 4,862,000.00

(b) Consumable supplies include water, food, medical supplies, and fuel for generators and vehicles. These supplies are dependent on the land force package and ISR package.

The water is estimated to be $9.38 per gallon (“Water,” 2011) and each person would require 7.38 gallons per day. Each Meals-Ready-to-eat (MRE) pack cost $7.25 (“MRE,” 2005) and each person would have 3 meals a day. The medical supply for each soldier is the USMC Individual First Aid Kit, which costs $107 (“First,” n.d.). The fuel for both generators and vehicles is estimated at $14 per gallon (“Energy,” 2011).

The supply of each consumable item is to last for 7 days and the costs for each package are stated below. The supplies that are dependent on land forces packages are water, food, medical supplies and fuel. The ISR packages would require supply of fuel for ISR generators.

Table 51. Costs of Consumable Supplies

Package-dependent supplies		**Costs**
Land forces packages	F1	$ 1,465,094.85
	F2	$ 1,684,658.39
	F3	$ 2,074,993.57
	F4	$ 3,124,019.36
ISR packages	C1	$ 14,670.54
	C2	$ 14,773.32
	C3	$ 31,416.94
	C4	$ 24,517.74

(c) The logistics costs for each COA are summarized below.

Table 52. Costs of Logistics for Each COA

Scenario	COAs	Threat Level	Land force and ISR packages	Cost ($)
Spratly Islands (Baseline)	COA 1	Low	F1 + C1	$ 17,503,411
	COA 2		F1 + C2	$ 17,503,411
	COA 3	Medium	F2 + C3	$ 19,405,706
	COA 4		F2 + C4	$ 19,350,168
	COA 5		F2 + C4	$ 19,350,168
	COA 6	High	F2 + C3	$ 19,405,706
Natuna Besar (Higher Level)	COA 7	Low	F3 + C1	$ 22,413,096
	COA 8	High	F4 + C3	$ 30,992,562
	COA 9	Medium	F4 + C3	$ 30,992,562
	COA 10		F4 + C4	$ 30,937,024

APPENDIX D. U.S. ARMY AND AIR FORCE PLATFORMS

A. JPADS

Figure 78. JPADS (from JPADS 2014)

- U.S. military airdrop system that utilizes precision of the GPS and steerable parachutes for precise point of impact on drop zone
- Able to carry extra light to heavy payloads
- Can receive weather updates and real-time adjustments during mission
- Stealthy with minimal visibility

Table 53. JPADS Specifications (after JPADS 2014)

Unit Cost	~US$68,000
Payload	Micro-light : 10 lbs Heavy: Up to 60,000 lbs
Accuracy	Up to 164–246 ft

B. FULTON SURFACE TO AIR RECOVERY SYSTEM ("STARS")

Figure 79. Fulton Recovery System (from Fulton 2007)

- Designed to retrieve persons on ground using compatible aircraft.
- Uses overall-type harness and self-inflating balloon attached to lift line
- Typically used in hard-to-reach places

Table 54. Fulton Recovery System Specifications (after Fulton 2007)

Main purposes:	Personnel recovery system Quick recovery
Designed for:	One or Two-Man retrievals
Tested with:	S2-Tracker Aircraft
Inducted from (year):	1958

C. AFSB (AFLOAT FORWARD STAGING BASE)

Figure 80. AFSB (from LaGrone 2014)

- Can be configured to work with helos configured with mine countermeasures and Special Forces.
- Features large helo landing pad and huge accommodations up to 250 troops
- Fast and efficient form of large-scale transportation
- Used as intermediate staging base for operations

Table 55. AFSB Specifications (after LaGrone 2014)

Main purposes:	Staging base for operations
Designed for:	MCMs, SOF
Unit cost:	~US$135,000,000

D. C-17 GLOBEMASTER III

Figure 81. C-17 Globemaster III (from Globemaster 2004)

- Unit Cost: 202.3 million (Globemaster 2004)

Table 56. C-17 Globemaster III (after rom Globemaster 2004)

Cruise speed	450 kts
Mission radius (extra tank)	Global with inflight refueling
Crew	3
Load	102 troops/paratroops; 36 litter and 54 ambulatory patients and attendants; 170,900 pounds (77,519 kilograms) of cargo (18 pallet positions)

E. C-130H HERCULES

Figure 82. C-130H Hercules (from Hercules 2003)

- Unit Cost: 30.1 million (Hercules 2003)

Table 57. C-130H Hercules Specifications (after Hercules 2003)

Cruise speed	318 kts
Mission radius (extra tank)	1050 NM
Crew	5
Load	6 pallets or 74 litters or 16 CDS bundles or 92 combat troops or 64 paratroopers, or a combination of any of these up to the cargo compartment capacity or maximum allowable weight.

F. MV-22 OSPREY

Refer to MV-22 OSPREY of Appendix B.

G. LOW ALTITUDE BALLOON

Refer to JLENS of Appendix C.

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APPENDIX E. RED FORCE PLATFORMS

A. *SHENYANG* J-15 CARRIER-STRIKE AIRCRAFT

Figure 83. Shenyang J-15 Carrier-Strike Aircraft (from CMO March 2013)

Table 58. Shenyang J-15 Specifications (after Shark February 2015)

Maximum Speed	Mach 2.4
Range	1781 NM (2050 mi)
Service Ceiling	65,700 ft
Rate of Climb	64,000 ft/min
Armament	8xPL-12/R-77 and 4xPL-9/R-73 AAMs, ECM pods, ASMs, ARMs

B. *LIAONING*, VARYAG-CLASS AIRCRAFT CARRIER

Figure 84. Aircraft Carrier, *Liaoning* (from CD August 2011)

Table 59. Aircraft Carrier, Liaoning Specifications (after Kreml 2011)

Displacement	59,100 tons (full-load), 67,500 tons (max-load)
Speed	32 knots
Range	3,850 NM
Endurance	45 days
Load	Total of 36 fixed-wing and rotary-wing aircraft

C. TYPE 071 AMPHIBIOUS LANDING SHIP

Figure 85. Type 071 Amphibious Landing Ship (from CMO March 2013)

Table 60. Type 071 Amphibious Landing Ship Specifications (after Chinese May 2013; Yuzhao July 2013)

Characteristics	
Displacement	20,000 tons
Speed	22 knots
Range	6,000 NM at 18 knots
Armament	1x AK-176 (76mm), 4x AK-630 (30mm)
Load	15-20 armored vehicles and 500–800 troops, 4x Z-8 *Super Frelon* helicopters, 4x Type 726 *Yuyi*-class Air Cushion Landing Craft

D. TYPE 052C DESTROYER

Figure 86. Type 052C Destroyer (from CMO March 2014)

Type 052C Destroyer Specifications (after Luyang 2015)

Table 61.

Displacement	7,000 tons
Speed	29 knots
Armament	48x HHQ-9, 8x C-805, 1x Type210, 2x Type 730, 6x torpedo tubes
Aircraft Carried	1x Kamov Ka-27 Helicopter

E. TYPE 022 *HOUBEI*-CLASS MISSILE BOAT

Figure 87. Type 022 Houbei-class Missile Boat (from Bussert 2007)

Table 62. Type 022 Houbei-class Missile Boat Specifications (after Lague 2012; Bussert 2007)

Displacement	224 tons
Speed	36 knots
Armament	8x C-801/802/803, 8x Hongniao, 12x QW-class MANPAD, 1x KBP AO-18

F. DF-21 ANTI-SHIP BALLISTIC MISSILE (ASBM)

Figure 88. DF-21 Anti-Ship Ballistic Missile (from CD 201)

Table 63. DF-21 Anti-Ship Ballistic Missile Specifications (after Kazianis 2013; Stokes 2009)

Range	956 NM (1,100 mi)
Speed	Mach 10
Payload	1323 lbs (600 kg)

APPENDIX F. OA ASSESSMENT METHODOLOGY

A. COA ASSESSMENT PROCESS

COA assessment was based on each system's performance for each MOE. The relative importance of each MOE was determined using stakeholder requirements interpreted by subject matter experts. The pairwise comparison technique was used to give each MOE a mathematically consistent weight commensurate to that MOE's perceived importance amongst all MOEs. The SME weight pairwise comparison is shown in Table 64, and percentage weights for the MOEs are shown in Figure 89.

Table 64. SME-Derived MOE Weights

	Detectability	Timeliness	Adequacy	Sustainability	Defendability	Weights
Detectability	1.00	0.50	0.33	0.50	0.50	0.10
Timeliness	2.00	1.00	5.00	2.00	2.00	0.37
Adequacy	3.00	0.20	1.00	2.00	2.00	0.22
Sustainability	2.00	0.50	0.50	1.00	2.00	0.18
Defendability	2.00	0.50	0.50	0.50	1.00	0.13

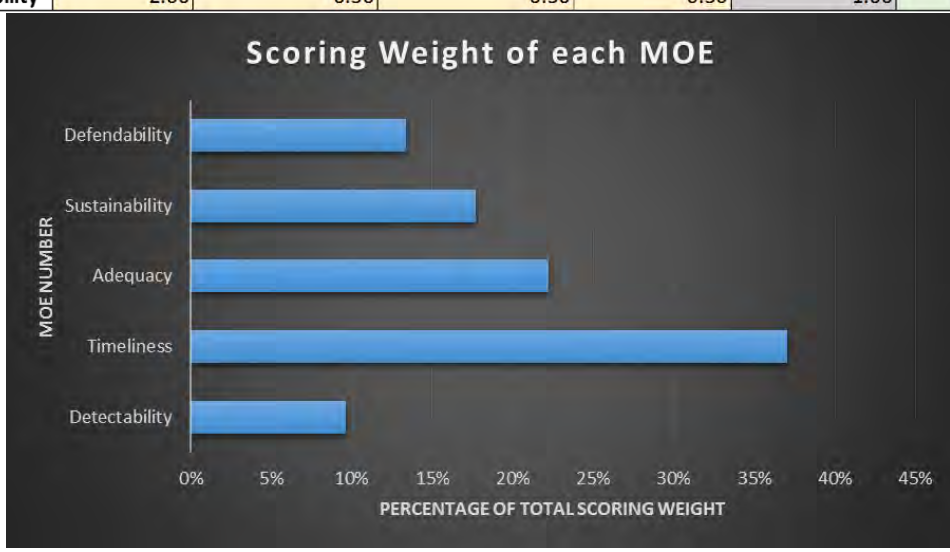

Figure 89. SME-Derived MOE Weights

During initial COA evaluation, it was determined that all COAs satisfied the adequacy and sustainability MOEs at an equal level. This was because the COAs were designed to include the number of platforms required to satisfy those two MOEs. This resulted in the detectability, sustainability, and defendability MOEs being used to differentiate COA performance.

B. MOE ASSESSMENT METHODOLOGY

1. Detectability

Detectability is based on the cardinal concept of distance. Since the exact range of detectability depends on the particulars of the target, the environment, the sensor and its transforms, the ranking of order of range is meant to be representative of the magnitude of distance between the various objects characterized by detectability. Therefore, detectability as characterized by range and therefore platform type is a crude cardinal representation by order of magnitude. A multiplicative value (cardinality) is then applied as a constant to maintain the order of magnitude difference between the six platforms. No arithmetic operations can be performed on ordinal numbers. Since order of magnitude characterization of detectability range is a cardinal concept, multiplication by the order of magnitude rankings is used to determine relative "stealth-ness" on a scale from 1 to 10 with 10 being the least detectable.

2. Timeliness

Individual performance scoring for the timeliness MOE is based on delivery systems. Each delivery system was evaluated using the Stochastic Get There First Model by building an AOI in the South China Sea, and placing blue and Red force origin locations in Singapore and Hainan Island respectively. Blue force speed was set according to delivery platform speed while Red force speed was set to 30 knots.

Each COA received a timeliness score based on its average performance 19 different time based scenarios ranging from a 96 hour head start over Red forces to a 12 hour delay. COA score was calculated from the scaled average performance of the COAs. Table 65 shows the performance of each COA for the timeliness MOE.

Table 65. First Arrival COA Performances

		Speed (kph)		Coverage																		
				Blue Head Start													Blue Delay					
COA	Plan of Movement	Blue Speed	Red Speed	-96	-88	-80	-72	-64	-56	-48	-40	-32	-24	-16	-8	0	2	4	6	8	10	12	Average
A	Ships Singapore	75	55	100%	100%	100%	100%	100%	100%	100%	100%	99%	94%	76%	65%	39%	36%	32%	28%	25%	21%	18%	28%
D	SSGN Singapore	37	55	97%	96%	95%	93%	89%	84%	76%	65%	54%	43%	43%	28%	16%	15%	13%	12%	10%	9%	8%	12%
B	LCAT Singapore	33	55	95%	93%	90%	87%	83%	76%	68%	57%	46%	37%	33%	24%	12%	11%	10%	9%	8%	7%	6%	9%
C	MV-22 Singapore	509	55	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%	97%	94%	89%	83%	76%	68%	59%	81%
D	C-17 Darwin	833	55	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	95%	91%	86%	79%	73%	66%	58%	78%

3. Adequacy

Adequacy measured each COA's ability to deliver 70% of the initial landing force with the initial wave of transport craft. This was measured by dividing the amount of landing force delivered by the initial force by the size of the total force.

Each COA was designed to deliver the full landing force as part of the initial package. Thus, all COA performed at the same level in the COA.

4. Sustainability

Sustainability was calculated using a combination of the percentage of the first 30 days of operations that supplies were maintained above a 70% threshold as well as the amount of time spent waiting to bring supplies above the that threshold.

Logistics modeling showed that all COA's were able to provide sufficient sustainment such that the landing force never dropped below the 70% threshold.

5. Defendability

COA Defendability scores were calculated using a combined scoring system that took into account air and surface detection ranges and the air and surface salvo equation for each of the 10 force packages to be delivered to the island. This combination of individual measurements resulted in four sub-measures that were weighted equally to determine an overall COA score in this MOE.

C. COA SCORE CALCULATION METHODOLOGY

The performance score for each delivery platform COA was calculated using Equation 1, which multiplies the decision maker’s assigned weighting for each MOE by the score each individual platform achieved in that MOE. It is important to recall that through metrics described in this chapter and in previous chapters, platform scores for MOEs have been determined and held constant before decision makers are able to set weights on MOE importance. Once set by the decision maker, the MOE weighting remains constant for each platform’s MOE score. This results in a “one-to-many” calculation, giving the decision maker consistent COA scores for overall performance.

$$\sum_{for\ all\ MOEs} MOE\ weight * MOE\ score$$

Equation 1: COA Score Calculation

From Equation 1, performance scores could be compared to pertinent independent variables such as cost or manning in order to also determine the optimality of each COA.

D. COA ASSESSMENT TOOL

Our team determined early in our COA evaluation process that MOE weighting could be variable based on a number of different factors. Decision maker preferences and operational factors could result in significant differences in MOE importance from our own stakeholder model. A COA Assessment Tool was created in order to facilitate COA evaluation under different MOE weights. This assessment tool allows a decision maker to alter the weights attached to each of the three MOEs. The assessment tool provides real time information as to which COAs score the best using cost and manning as scoring criteria. The techniques used to create this assessment tool make it scalable and capable of including many more MOEs and scoring criteria, if desired.

Figure 91 shows a visual representation of the assessment tool output when configured for the stakeholder requirements and derived MOE weighting used for the team’s scenario, analysis, and conclusions. Figure 92 offers the reader a look at some different outputs from equal MOE weighting. Figures 93–95 show the extremes in for

100% MOE weighting assigned to each of detectability, timeliness, and defendability, respectively.

Figure 90. Flexible System Assessment Tool: Scenario Weights

Figure 91. Flexible System Assessment Tool: All Equal Weights

Figure 92. Flexible System Assessment Tool: 100% Detectability

Figure 93. Flexible System Assessment Tool: 100% Timeliness

Figure 94. Flexible System Assessment Tool: 100% Defendability

For this project it was determined that it would be useful to measure COA performance against both cost and manning. Costs were calculated based on 30 day operational costs of the platforms, platform manning, sustainment, and force package manning for each COA. The scatter plots shown plots each COA's score against its normalized price and normalized force package and platform manning. These two independent variables were chosen as indications of the amount of resources needed to

affect the COA as well as the amount of resources placed inside the A2AD area. The scatter plot is designed so that the most optimal solution possible will achieve a score of 1.0, 1.0 in the upper right of the plot; the closer a COA's point is to the optimal, the better that COA's overall performance relative to that particular independent variable and the set MOE weights. Each scatter plot is accompanied by a graph that shows the overall distance of that point from the optimal 1.0, 1.0 position. The distance is calculated using Equation 2.

$$Distance\ from\ optimal:$$
$$= \sqrt{((1 - COA\ Score)^2 + (1 - Normalized\ Independent\ Variable\ Score)^2)}$$

Equation 2: COA SCORE DISTANCE CALCULATION

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